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Highway Runoff Water Quality Literature Review

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Abstract: The Ontario Ministry of Transportation (MTO) initiated a literature review in order to update its knowledge of stormwater quality, particularly that associated with highways in various countries in Europe. The considerable material reviewed is grouped under two headings:

1. the quality of stormwater as it leaves an operating highway; and
2. the degree of improvement as this water enters and flows in the receiving watercourse.

Several studies in North America and Germany have reported that levels of pollutants in the runoff generated from operating highways are normally low. One U. S. Federal Highway Administration (FHA) study concluded that rural highways having less than 30,000 vehicles per day do not make a significant impact on most receiving waters. Guidelines produced by the FHA indicate that highway runoff is unlikely to have adverse effects on receiving waters when:

1. no public water supply is involved in the receiving waters
2. the highway has less than 30,000 vehicles as the average daily traffic, or
3. the highway runoff is conveyed by overland flow in an unlined or grassed channel, at least over a distance of 60 m prior to discharging into the receiving stream, or
4. the dilution ratio of the highway runoff to the receiving stream is at least 100 to 1.

Water quality effects from highway runoff have not been covered adequately in the literature. The closest references to highway runoff effects are contained in the urban stormwater literature. Although the nature and concentration of pollutants may be similar in urban and in highway runoff, the relative loadings are often much higher in urban runoff. Pollutants from operating highways have the greatest effects on aquatic environments when traffic volumes are very high, i.e., greater than 185,000 vehicles per day.

The control of sediment to which the most serious pollutants become adsorbed during transport may be the most effective strategy to mitigate stormwater quality impacts.

Comments:

Key Words:

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HIGHWAY RUNOFF WATER QUALITY
LITERATURE REVIEW - SUMMARY

The Ministry of Transportation is committed to introduce a storm water quality management policy and as a first step, has initiated a literature review of storm water quality, generated from highways.

The following review is based on North American, United Kingdom, German and Scandinavian literature, addressing the highway runoff quality issues.

The considerable material reviewed is grouped under two headings:

A) the quality of stormwater as it leaves an operating highway; and

B) the degree to which the quality of stormwater improves as it passes through a variety of paths.

At the end of each group's review, a summary is presented. The conclusions for Group A, "on the quality of stormwater as it leaves an operating highway," are broken down for different situations, focusing the conclusions under the headings of land use, lanes of highway, climate, type of drainage facilities, type of pavement, etc.

Some of the individual water quality samples collected during the monitoring programs in the U.S., U.K. and Continental Europe showed elevated level of pollutants.

Kerri, K.D. et al. (1985) states that urban highways in California, where no accidental spills occur, do not produce large amounts of pollutant constituents during storm runoff events. Highways, which drain between 1 and 2 hectares of completely paved areas, and have six to eight lanes, produce pollutant loads in runoff water which are sufficiently low, so that costly treatment facilities are not needed to meet water quality objectives.

According to the German experiments (Stotz, G., 1987), only 5-20% of the total pollution arising from motor vehicle traffic is discharged with the runoff. The rest is disposed by wind, vehicular turbulence or spread onto the shoulder of the highway.

Generally, highway runoff contains pollutant levels comparable to urban runoff.

The U.S. Federal Highway Administration Research Report on Effects of Highway Runoff on Receiving Waters, Vol. II, August 1985, concluded that rural highways with traffic volume under 30,000 vehicles per day exert minimal or no impact on the aquatic components of most receiving waters.

The U.S. Federal Highway Administration report on Management Practices for Mitigation of Highway Storm Water Runoff Pollution, Volume I, Guidelines, 1985, states the following conditions when highway runoff is not likely to have adverse effects on receiving waters:

1. No public water supply involved in the receiving waters.

2. The highway has less than 30,000 vehicles as the average daily traffic (ADT), or

3. The highway runoff is conveyed by overland flow in an unlined or grassed channel, at least over a distance of 60 m, prior to discharging into the receiving stream, or

4. The dilution ratio between highway runoff and receiving streamflow is at least 100 to 1.

Water quality effects on receiving waters are assessed according to the increases in concentration or loading of a particular pollutant over background conditions. The possible impacts are compared to the criteria established for water quality standards.

There are a set of water quality criteria guidelines assembled in the Federal Highway Administration publication on Effects of Highway Runoff on Receiving Waters, Volume 3, 1985. (See Tables in Appendix, which summarize the water quality criteria for different constituents of highway runoff.)

Water quality effects from highway runoff have not been covered adequately in the literature. The closest reference to highway runoff effects are contained in the urban storm-water literature. Although the nature and concentration of pollutants may be similar in urban and in highway runoff, but the relative loadings are often much higher in urban runoff.

A brief summary of the highway generated pollutants and their effects are presented below, based on the same Effects of Highway Runoff on Receiving Waters, Volume 3, publication.

- Dissolved Oxygen Depletion. Generally the BOD is less than 30 mg/L, based on urban stormwater data. There is no data on BOD for highway runoff.

- Nutrients. Urban stormwater runoff can, in some cases, contain ammonia and nitrate levels in excess of those recommended by EPA for public health reasons. Excessive nutrients can also create accelerated growth of nuisance aquatic plants in water bodies. Such conditions have been reported for urban stormwater but not for highway runoff alone.

- De-icing Agents. The use of de-icing agents and their effect on receiving waters and nearby soils is well documented in the literature.

  Generally, the effect in streams and rivers were less pronounced, where dilution, especially during rain or melt conditions, managed to keep the chloride levels below the Canadian and U.S. EPA criteria of 250 mg/L. For lakes and wetlands, road salts can show high accumulation above the above criteria.

- Metals. Highway runoff contains metals, but few field studies have shown elevated metals concentration in the water. The observed high metal content of sediments implies a rapid removal of metals by sedimentation.

  Metal concentration in highway runoff sediments can be an order of magnitude higher than the background sediments.

Receiving waters serve as a primary sink for the particulates associated with elevated metals.

Sediment collected from bridge deck runoff can contain twice as high metal concentrations, as sediment which has first passed overland through vegetated ditches.

Metal concentration in sediments showed close correlation with ADT on roads draining to receiving waters.

- Biological impacts were studied by bioassay experiments based on actual highway runoff. Algal assays found severe inhibition when exposed to 1, 5 and 10% of runoff from highway with very high ADT of 185,000, after two weeks of antecedent dry weather. However, runoff from 23,000 and 16,000 ADT in rural and suburban highways, with short antecedent dry days, was generally stimulatory to algal populations.

  Bioassays with rainbow trout from highway runoff with ADT of 50,000 showed no toxic effects with filtered runoff, but unfiltered runoff was toxic with both a 50% dilution and with an undiluted sample. Similarly, runoff filtered through a 60 m grassy ditch was not toxic to the trout. Unlike the algal experiments, pollutants associated with particulates can be deleterious to rainbow trout.

  Bioassays showed minimal acute toxicity of undiluted highway runoff for amphipod, isopod, water flea, mayfly and fathead minnows. Although decreases in abundance and diversity of benthic organisms has been attributed to urban runoff, these effects have not been shown for highway runoff. Similarly, urban runoff

discharges have been implicated in accelerated entrophication of lakes, while highway runoff loadings by themselves, have not shown to have this effects.

When salt concentration in the receiving waters exceed 1,000 mg/L chloride, it has been shown to increase the drift of benthic microinvertebrates, decrease the biomass and diversity of algal species and increase the density of bacteria in streams.

The second part of the literature review deals with the various alternative measures available to mitigate the effect of pollutants. First the various planning, design and regulation measures are listed which could prevent some of the pollutants entering the highway system.

The next group of measures listed are applied after the pollutants are deposited, but before washed off by runoff.

The last group of measures, which are the most common, deal with the pollution issue after the runoff has occurred.

A.1 THE QUALITY OF STORMWATER AS IT LEAVES AN OPERATING HIGHWAY

The literature review first presents the U.S. information which is based mostly on the series of volumes released by the U.S. Federal Highway Administration. This is followed by some European literature. Pollutant concentrations and loadings are presented, obtained from monitoring and analyzing highway runoff.

The next group of literature review describes information on highway pollutants obtained from sweeping and flushing. Although not all highway pollutants collected by sweeping and flushing would end up in highway runoff, the information can provide some useful data.

The final part of Chapter A reviews the literature on sources and migration of highway pollutants.

The common highway runoff constituents and their primary sources are presented in Table 1, collected from information published by the U.S. Federal Highway administration in Sources and Migration of Highway Runoff Pollutants Vol. I, 1984. (Kobriger N.P., Geinepolos, A).

A.1.1 U.S. Literature

The most extensive investigation involving monitoring of four different highway locations across the U.S. was reported in the Sources and Mitigation of Highway Runoff Pollutants, a four volume document prepared for the U.S. Federal Highway

TABLE 1

COMMON HIGHWAY RUNOFF CONSTITUENTS AND THEIR PRIMARY SOURCES

Constituent	Primary Source
Particulates	Pavement wear, vehicles, atmosphere, highway maintenance
Nitrogen, phosphorous	Atmosphere, roadside fertilizer application.
Lead	Leaded gasoline (auto exhaust), tire wear (lead oxide filler material), lubricating oil and grease, bearing wear
Zinc	Tire wear (filler material), motor oil (stabilizing additive), grease
Iron	Autobody rust, steel highway structures (guardrails, etc) moving engine parts
Copper	Metal plating, bearing and bushing wear, moving engine parts, brake lining wear, fungicides and insecticides applied by maintenance operations
Cadmium	Tire wear (filler material), insecticide application
Chromium	Metal plating, moving engine parts, brake lining wear
Nickel	Diesel fuel gasoline (exhaust) and lubricating oil, metal plating, bushing wear, brake lining wear, asphalt paving
Manganese	Moving engine parts
Bromide	Auto exhaust
Cyanide	Anticake compound (ferric ferrocyanide, Prussian Blue or sodium ferrocyanide, Yellow Prussiate of Soda) used to keep deicing salt granular
Sodium, Calcium	Deicing salts, grease
Chloride	Deicing salts
Sulphate	Roadway beds, fuel, deicing salts

TABLE 1

COMMON HIGHWAY RUNOFF CONSTITUENTS

AND THEIR PRIMARY SOURCES

(continued)

Constituent	Primary Source
Petroleum	Spills, leaks or blow-by of motor lubricants, antifreeze and hydraulic fluids, asphalt surface leachate
Polychlorinated biphenyls, pesticides	Spraying of highway right-of-ways, background atmospheric deposition, PCB catalyst in synthetic tire.
Pathogenic bacteria (indicators)	Soil, litter, bird droppings, and trucks hauling livestock and stockyard waste.
Rubber	Tire wear.
Asbestos	Clutch and brake lining wear.

Administration. The most pertinent part of the work relating to the above topic is contained in Volume 3, Research Report, prepared by Kobriger, N.P., and Geinepolos, A., released in 1984.

The following pages (4-22) summarize the research results, listing the quality of runoff found during the monitoring program. First, the characteristics of the four monitoring sites are presented, followed by the results of the runoff monitoring. Concentrations and loadings in the tables show median or mean values.

Below is a list of the four sites used in the U.S. monitoring program, including the average daily traffic (ADT) counts which were found to be one of the most significant factor influencing the quality of stormwater leaving a highway.

Location	Type	ADT	Surface	No. of Lanes	Drainage Area-Acre
Milwaukee, Wisconsin (I-94)	Urban	116,000	Asphalt	8	7.6
Sacramento, Calif. (Hwy. 50)	Urban	85,900	Concrete	8	2.5
Harrisburg, Pennsylvania (I-81)	Rural	27,800	Concrete	4	2.8
Efland, North Carolina (I-85)	Rural	25,000	Asphalt	4	2.5

In almost all cases, the Milwaukee and Sacramento test areas showed higher pollutant contents than the other two sites. As both high ADT sites are in urban areas, the results cannot be interpreted to indicate separately the influence of high ADT and the effect of an adjacent urban land use on highway runoff quality. However, a set of precipitation data taken at urban and rural areas, are presented in Chapter A.3.1 as indicators to assess the effect of urban areas on the quality of storm runoff discharged from a highway.

Solids

The main carrier pollutant in highway runoff is the total solid content. It exhibits the highest degree of association with other pollutants. The other carrier which shows close correlation is the suspended solid content.

Generally, the sites with higher ADT values gave higher concentration and loading of solids (Tables 1.1, 1,2, 1.3).

Another important factor to note is the increase in concentration of solids during the winter period. This is caused by the use of deicing agents and the effect of frost, which reduces the movement of solids caused by wind and vehicle turbulence.

TABLE 1.1
MEAN CONCENTRATION OF SOLIDS (mg/L)

Site	TOTAL SOLIDS		SUSPENDED SOLIDS	
	Non-winter	Winter	Non-winter	Winter
Milwaukee	381	3 260	157	461
Sacramento	204	-	106	-
Harrisburg	550	837	345	327
Efland	125	441	23	20

The higher concentration at Harrisburg comes from the unvegetated drainage ditch. The overall higher winter concentrations are caused by the de-icing agents.

TABLE 1.2
RUNOFF LOADING OF SOLIDS
PER EVENT (mg/km)

Site	TOTAL SOLIDS		SUSPENDED SOLIDS	
	Non-winter	Winter	Non-winter	Winter
Milwaukee	100	704	39	100
Sacramento	78	-	40	-
Harrisburg	9.5	236	6	92
Efland	65	181	12	8.8

The low Harrisburg loading figures are caused by the small runoff volumes monitored. Efland had high runoff values during the non-winter season, which is reflected in the loadings, when compared with the Harrisburg measurements.

TABLE 1.3
RUNOFF LOADING OF SOLIDS PER RUNOFF VOLUME
(kg/km per cm)

Site	TOTAL SOLIDS		SUSPENDED SOLIDS	
	Non-winter	Winter	Non-winter	Winter
Milwaukee	176	1 520	73	214
Sacramento	78	-	41	-
Harrisburg	156	237	76	93
Efland	41	142	7.5	6.5

Metals

Data on lead, zinc, iron, chromium, copper, cadmium, nickel and arsenic were collected at the four monitoring sites.

Again, the two sites with the high ADT values, Milwaukee and Sacramento showed the higher concentration of metals than the other two lower ADT sites (Tables 1.4, 1.5).

The higher iron content at Harrisburg is caused by the high iron content in the local soils. As expected, the winter values are higher than the non-winter ones. Generally, lead and zinc concentrations are strongly influenced by vehicular traffic.

Median lead, zinc and iron concentrations increased in the winter period, while chromium, copper, calcium and nickel concentrations showed no seasonal trends. Small or undetectable loadings of chromium, cadmium, nickel and arsenic were observed at most monitoring stations.

TABLE 1.4

HIGHWAY RUNOFF, MEDIAN CONCENTRATION OF METALS (mg/L)

	MILWAUKEE		SACRAMENTO		HARRISBURG		EFLAND	
	Non-Winter	Winter	Non-Winter	Winter	Non-Winter	Winter	Non-Winter	Winter
Lead	0.6	2.5	0.4	-	ND	0.04	0.02	0.02
Zinc	0.355	1.3	0.264	-	0.176	0.164	0.049	0.058
Iron	4.92	21.2	3.95	-	16.1	11.1	2.13	3.25
Chromium (10^{-2})	ND	5.0	ND	-	5.0	ND	0.2	0.3
Copper	14	22	7.0	-	9.5	4.3	4.4	2.4
Cadmium (10^{-2})	ND	2.0	1.5	-	ND	ND	ND	ND
Nickel	ND	0.10	0.07	-	0.05	ND	0.01	ND

Mercury and arsenic non-detectable (ND) in most samples.

TABLE 1.5
HIGHWAY METAL LOADINGS OF RUNOFF VOLUME
(kg/km per cm)

	MILWAUKEE		SACRAMENTO		HARRISBURG		EFLAND	
	Non-Winter	Winter	Non-Winter	Winter	Non-Winter	Winter	Non-Winter	Winter
Lead	0.28	1.16	0.15	-	ND	0.011	0.004	0.006
Zinc	0.18	0.59	0.11	-	0.05	0.05	0.016	0.021
Iron	2.28	9.84	1.50	-	4.57	3.14	0.68	1.05
Chromium	ND	0.02	ND	-	0.011	ND	0.0006	0.001
Copper	0.06	0.10	0.02	-	0.02	0.01	0.01	0.007
Cadmium	ND	0.009	0.005	-	ND	ND	ND	ND
Nickel	ND	0.046	0.02	-	ND	ND	0.003	ND

Mercury and arsenic non-detectable (ND).

Normalized data for 1 cm of runoff volume (Table 1.5) showed that non- winter lead and zinc loadings are related to average daily traffic.

Higher winter loadings come from increased surface loading due to lack of sweeping, less atmospheric blow-off and reduced runoff caused by freezing weather, stop and go traffic and increased body rusting.

De-Icing Agents

The principal de-icing agents used at the three U.S. monitoring sites were sodium chloride and calcium chloride. No de-icing agents were used at the Sacramento site. Both concentration (Table 1.6) and loading figures (Table 1.7) were very high during the winter periods. Principally, sodium chloride and calcium chloride are used in the U.S. Much of the chlorides end up in the receiving streams. Sodium and calcium are carried by mainly clay particles. As expected, there are large differences between winter and non-winter concentrations.

In a smaller scale monitoring program done by Dillon (1989), runoff from three sites were analyzed to determine the salt concentration in runoff:

i) Storm water collected from the Don Valley Corridor ranged in chloride concentration between 200-4650 mg/L. The highest values were recorded in November, January and early April. Background values were close to 300 mg/L.

TABLE 1.6
DEICING AGENTS, CONCENTRATION IN HIGHWAY RUNOFF - (mg/L)

	SODIUM		CALCIUM		CHLORIDE	
	Non-Winter	Winter	Non-Winter	Winter	Non-Winter	Winter
Milwaukee	159	1450	14	59.3	82.9	2360
Sacramento	18.6	-	19	-	12.6	-
Harrisburg	16	43.9	15	20	22.1	61.1
Efland	3.1	90.4	-	13.8	19.2	202

TABLE 1.7
DEICING AGENTS, LOADING PER RUNOFF VOLUME
(kg/km per cm RUNOFF)

	SODIUM		CALCIUM		CHLORIDE	
	Non-Winter	Winter	Non-Winter	Winter	Non-Winter	Winter
Milwaukee	74	675	6.5	27.5	38.5	1064
Sacramento	7.1	-	7.2	-	4.8	-
Harrisburg	4.5	12.4	4.2	5.6	6.2	17.3
Efland	1.0	29	-	4.4	2.1	65

ii) In a Richmond Hill residential area (Mill Pond), the concentration values in storm water were lower ranging from 197 - 1700 mg/L at a 2 ha site and 72-750 mg/L at another site which collects runoff from a 10 ha area. Background concentration values were below 100 mg/L.

iii) The third site in Thornhill (Oakland Pond), gave the lowest values ranging from 87 to 175 mg/L.

Results of the Dillon monitoring program are plotted on the enclosed figure.

The subsequent material presented up to Chapter A.1.2, follows the previously referenced work done by Kobriger, N. P. and Geinopolos, A. (1984).

Oil and Grease

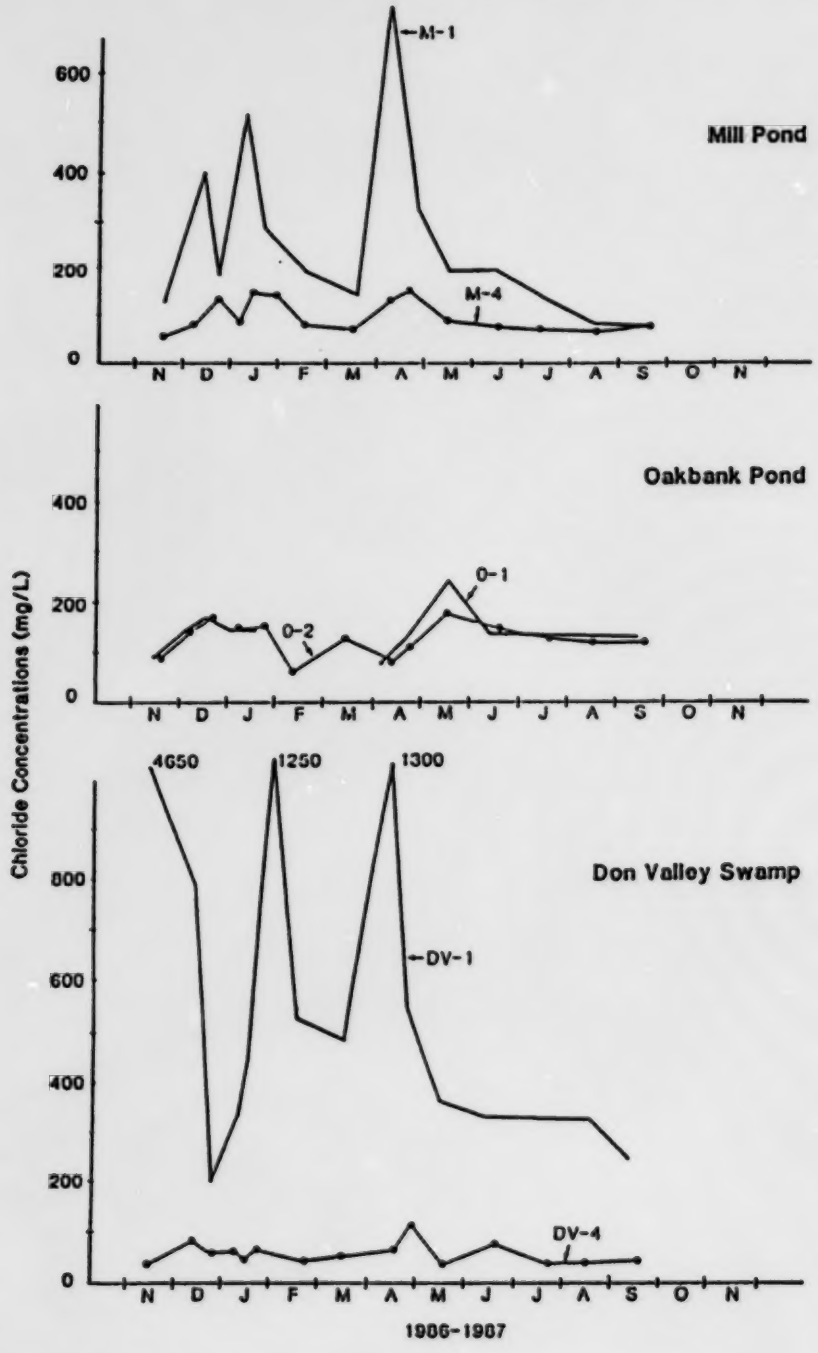
Only limited data are available from three of the four U.S. sites. The correlation with ADT is not very clear, as shown in Table 1.8.

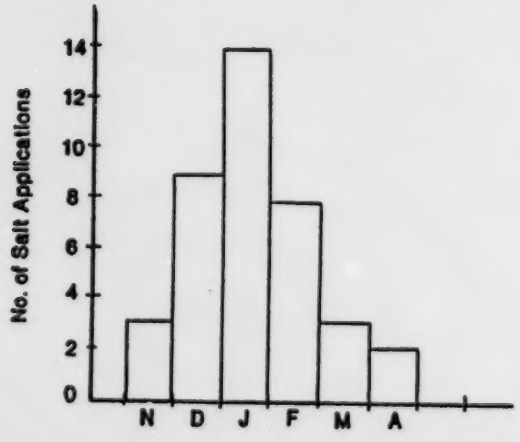
Nutrients

Generally, nutrient concentrations in highway runoff are similar to those observed in urban runoff (see Tables 1.9, 1.10 and 1.11). The nitrogen concentration tends to be lower in urban runoff, while phosphate concentration is generally higher in urban runoff.

Oxygen Demand Parameters

Only chemical oxygen demand (COD) and total organic carbon (TOC) tests are available. Biological oxygen demand (BOD_5) analysis was found to be inappropriate for urban runoff by the two authors.





Chloride Concentrations at the Study Sites

DILLON

TABLE 1.8
OIL AND GREASE CONCENTRATION AND LOADING IN HIGHWAY RUNOFF

	MEAN CONCENTRATION (mg/l)		MEAN LOADING kg/km RUNOFF PER cm	
	Non-Winter	Winter	Non-Winter	Winter
Milwaukee	5	13	2.5	6.0
Sacramento	11	-	4.3	-
Harrisburg	-	-	-	-
Efland	7	-	2.3	-

TABLE 1.9
PHOSPHATE CONCENTRATION AND LOADING OF NUTRIENTS IN HIGHWAY RUNOFF

	MEAN CONCENTRATION (mg/l)		MEAN LOADING kg/km RUNOFF PER cm	
	Non-Winter	Winter	Non-Winter	Winter
Milwaukee	0.33	0.54	0.15	0.25
Sacramento	0.44	-	0.16	-
Harrisburg	1.18	0.60	0.33	0.17
Efland	0.16	0.11	0.05	0.04

TABLE 1.10
TOTAL KJELDAHL

	MEAN CONCENTRATION (mg/l)		MEAN LOADING kg/km RUNOFF PER cm	
	Non-Winter	Winter	Non-Winter	Winter
Milwaukee	2.88	3.41	1.86	1.58
Sacramento	2.03	-	0.77	-
Harrisburg	2.19	1.17	0.62	0.33
Efland	1.18	2.00	0.38	0.64

TABLE 1.11
NITRATE AND NITRITE

	MEAN CONCENTRATION (mg/l)		MEAN LOADING kg/km RUNOFF PER cm	
	Non-Winter	Winter	Non-Winter	Winter
Milwaukee	0.66	0.83	0.31	0.38
Sacramento	0.33	-	0.12	-
Harrisburg	4.37	6.20	1.24	1.76
Efland	0.08	0.24	0.02	0.08

A comparison of both COD and TOC tests from highway runoff and urban runoff showed very similar results.

TABLE 1.12
CONCENTRATION OF TOC AND COD IN HIGHWAY RUNOFF - (mg/l)

Site	MEAN TOC		MEAN COD	
	Non-Winter	Winter	Non-Winter	Winter
Milwaukee	27	83	92	326
Sacramento	19	-	55	-
Harrisburg	18	13	42	21
Efland	-	23	-	67

TABLE 1.13
LOADING OF TOC AND COD IN HIGHWAY RUNOFF
kg/km/per cm RUNOFF

Site	MEAN TOC		MEAN COD	
	Non-winter	Winter	Non-winter	Winter
Milwaukee	12.5	38.7	43	152
Sacramento	7.4	-	21	-
Harrisburg	5.1	3.7	12	6.0
Efland	-	7.5	-	21.4

Sulfate

Sulphuric acid is the main component of acid rain, but catalytic converters can also produce sulphuric acid.

There was quite a wide variation of sulphates recorded at the four U.S. sites, see table below:

TABLE 1.14
CONCENTRATION AND LOADING OF SULPHATE IN HIGHWAY RUNOFF

Site	CONCENTRATION (mg/L)		LOADING kg/km per cm Runoff	
	Non-Winter	Winter	Non-Winter	Winter
Milwaukee	10	56	4.6	25.8
Sacramento	6	-	1.3	-
Harrisburg	20	19	5.6	5.5
Efland	7	11	2.2	3.4

pH

Precipitation at the four U.S. monitoring sites were characterized as acid. The highway buffering capacity to neutralize the acid rain comes from highway dust and dirt, calcium carbonate and calcium sulfate in concrete paving, drainage ditch soils and deicing agents.

TABLE 1.15
MEAN pH VALUES

Site	Mean Rainfall	Mean Runoff
Milwaukee	3.75	7.0
Harrisburg	4.40	7.0
Sacramento	5.25	6.6
Efland	4.31	6.4

Bacteria Counts

Bacteria counts were higher in the fall samples than in the spring.

The fecal coliform (FC) and fecal streptococci (FS) ratios were mostly below 0.7, which indicates animal origin.

Interestingly, the data showed that the FC/FS ratio is consistently low where the runoff is conveyed through a grassy area (Harrisburg and Efland).

TABLE 1.16
BACTERIA COUNTS/100 mL

Site	Fecal Coliform	Fecal Strep.	FC/FS
Harrisburg			
- paved	250 - 660	5300 - 127000	0.03 - 0.07
- unpaved	10 - 20	5600 - 10900	0
Sacramento			
- paved	350 - 4600	2400 - 11000	0.16 - 1.0
Efland			
- paved	570 - 730	11000 - 16000	0.05
Milwaukee			
- paved	1 - 100 000	40 - 100 000	0.04 - 12.8
- unpaved	19 - 150	3750 - 15 000	0.005 - 0.01

Roadway surfaces can become periodically seeded with debris containing enteric bacteria. One possible source could be trucks carrying livestock and stockyard waste. Fecal coliform can remain viable within the dust and dirt for at least seven weeks.

Fecal coliform and fecal streptococcus bacteria remain viable in stagnant storm sewer water for at least 13 days.

PCB

Low level of PCBs are transported in highway runoff. Possible sources are:

- Atmospheric deposition, industrial smoke, aircraft engine exhaust.

- Pesticide application, which have PCB additives.

- Accidental spills.
- Breakdown of additives used in vehicles.
- Synthetic tires.

Milwaukee site showed 229 micrograms/kg in dry soil. Loading for the same site was 0.0006 kg/km.

Runoff samples had the following concentrations: 0.93, 1.6, 0.13, 0.17, 0.16 microgram/L.

The high contaminant levels may be attributed to a major power transformer station downwind of the site. At another site, paved and unpaved runoff samples were compared. Concentrations of PCBs were comparable: 0.15 and 0.16 µg/L respectively. Sources include precipitation, highway dust and dirt and contaminated soil eroded by runoff from unpaved surfaces adjoining to the highway. Atmospheric deposition, likely the highway system's main source of PCB's, has been estimated at 50 µg/m²/year over Lake Michigan and its watershed.

Unpaved Runoff

Runoff coefficient for unpaved areas ranged from 0.02 to 0.19 (Milwaukee = 0.02, Sacramento = 0.09, Harrisburg = 0.19).

Runoff from unpaved areas were observed mainly on frozen ground or from large rainfall events.

A comparison of paved and unpaved loading is presented in Table 1.17.

TABLE 1.17
COMPARISON OF LOADINGS FROM PAVED AND UNPAVED RUNOFF EVENTS - kg/EVENT

Parameter	MILWAUKEE		SACRAMENTO		HARRISBURG	
	Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
TS	130	2.5	16.6	1.34	13	13
TVS	21	0.7	6.0	0.36	1.19	2.80
SS	26	0.15	8.6	0.76	5.4	6.3
VSS	12	0.08	2.2	0.12	0.2	0.26
TOC	0.8	0.16	2.53	0.19	0.41	1.00
COD	29.4	0.38	7.2	0.31	0.78	1.33
Pb	0.1	0.0003	0.01	0.001	0.00022	0.00013
Zn	0.1	0.0009	0.02	0.0009	0.0027	0.004
Fe	1.6	0.009	0.32	0.068	0.19	0.16
Cr	0.001	ND	0.0002	ND	0.00003	ND
Cu	0.03	0.004	0.009	ND	0.00004	0.0013
Cd	0.0004	ND	0.0004	ND	ND	ND
Ni	0.001	ND	0.0027	0.0013	ND	ND
Hg	ND	ND	ND	ND	ND	ND
PO_4-P	0.07	0.003	0.05	0.0045	0.009	0.009
TKN	0.53	0.02	0.21	0.013	0.018	0.036
NO_2 + NO_3	0.12	0.003	0.02	ND	0.077	0.09
Na	89.8	1.04	-	-	0.40	0.19
Cl	96.6	0.74	1.22	0.03	0.45	0.45
Ca	4.0	0.16	-	-	0.91	0.33
SO_4	2.93	0.09	0.31	0.018	0.26	0.30
Oil and Grease	1.4	-	-	-	-	-

The unpaved area runoff pH was 6.4 - 7.4, similar to paved runoff pH.

Generally, the median loading value for paved runoff events was an order-of-magnitude higher than for unpaved runoff. Therefore, the contribution of the unpaved area to the total constituent loading is negligible.

Summary

While the previous tables gave median or mean values, the summary in Table 1.18 presents the entire range from minimum to maximum.

The pollutant loadings are only available per runoff events, not for unit (1 cm) runoff as presented for the four individual sites.

Additional information obtained from European literature follows.

TABLE 1.18
SUMMARY OF HIGHWAY RUNOFF COMPOSITE QUALITY DATA FOR ALL FOUR MONITORING SITES - OVERALL MONITORING PERIOD

Parameter	Pollutant Concentration (mg/L)		Pollutant Loading (kg/km/event)	
	Minimum	Maximum	Minimum	Maximum
pH	4.90	7.95		
TS	68	57,400	0.24	4,900
VTS	10	510	0.07	338
SS	6	2,160	0.06	1,714
VSS	4	317	0.01	258
Pb	ND	6.30	ND	5.7
Zn	0.036	2.90	0.0001	2.1
Fe	0.30	115	0.003	42.2
Cr	ND	0.19	ND	0.15
Cu	ND	0.59	ND	0.54
Cd	ND	0.06	ND	0.002
Ni	ND	0.22	ND	0.18
Hg	ND	0.001	ND	0.0002
As	ND	0.03	ND	0.03
Na	2.1	22,500	0.005	3,550
Ca	4.0	450	0.26	57
Cl	2.0	35,000	0.02	3,805
Oil and Grease	1	21	0.08	19.4
PO_4-P	0.03	4.45	0.003	3.2
TKN	ND	9.80		4.3
NO_2+NO_3	ND	9.00		2.4
TOC	4	182	0.69	120
COD	16	660	1.38	540
SO_4	ND	180		14.3

ND = Not Detectable.

A.1.2 European Literature

The following pages summarize results of highway runoff monitoring reported from Europe. All experiments were on a much smaller scale than the U.S. monitoring, reported on the previous pages.

1. Sampling of runoff from U.K. urban motorways (Hedley and Lockley, 1975), gave the following values collected over a 12 month period.

   Suspended Solids started to rise just before the winter salting. The first peak occurred in December, followed by a week in January. Volatile SS concentrations generally followed the same pattern. The range of SS concentration was 160 - 2238 mg/L.

   Heavy Metals. Total metals exhibited the same two peaks during the winter period. The range of concentration was 1.39 - 15.01 mg/L.

   BOD appeared to show a threefold increase on the summer concentrations, with a maximum over 100 mg/L during December/January.

   Additional Miscellaneous Data

   Cleaning operations included twice a month of road gullies, drainage channels, sedimentation chambers and road surface. This removed 13.3 t/month from the study area (36 000 m^2).

   Salt application rate was 14-56 g/m^2.

Atmospheric fallout was 116 t/km².

ADT = 66 000 - 77 000.

From the study area, 5 t/annum rubber was collected.

Zinc peak loading in January did not come just from salt, it was also influenced by the corrosion factor. Concentration ranged from 0.65 - 8.01 mg/L. Lead loading was lower than expected, possibly due to wind effect, and showed greater losses during the summer with drier road surfaces. Concentrations ranged from 0.45 - 4.9 mg/L.

Copper concentration was below 3 mg/L. Nickel and cadmium peaked following salting.

2. Pollution Transport From a Highway (E. Lygren, E. Gjessing, L. Berglind, Norwegian Institute for Water Research 1984). The Science of the Total Environment, 33 (1984) 147-159. Elsevier Science Publishers B.V., Amsterdam

In Norway, a considerable amount of pavement dust is produced during a year, particularly during the winter season when studded tires are used on vehicles. The asphalt wear, when using these tires is estimated to be 20-50 g/km/vehicle. This matter will partly be deposited on the road surface and partly be transported through the atmosphere to the surrounding area, together with other motor traffic pollutants.

A three-year program was aimed at characterizing the nature and the fate of the particulate matter from a highway. The characterization included studies on particle-size distribution, heavy metal concentration and contents of organic micropollutants, such as PAH.

The pollution transport from a highway with an average traffic density of 8,000 vehicles per day (ADT) has been measured during a period of two and a half years.

It was found that a major part of the pollutants from a highway was deposited 5-25 m from the road. Further, it was observed that an essential part of the pollutants were "produced" through the snow accumulation period and released during the spring period. The period of snowmelt thus gave the most important effects on the surface water.

In the Norwegian monitoring study, the following range of concentration of pollutants were observed in surface runoff.

pH	6.7. - 9.1	
COD	50 - 850	mg/L
TOC	8 - 320	mg/L
Ni	5 - 436	µg/L
Cr-T	9 - 190	µg/L
Zu	91 - 740	µg/L
Pb	62 - 920	µg/L
Cd	1 - 28	µg/L
Fe	3.1 - 78	mg/L
Hg	0.19 - 13.2	µg/L
Ca	3.1 - 85.1	mg/L
Cu	10 - 430	µg/L
Cl	2 - 3100	mg/L
SO_4	4.9 - 520	mg/L
PAH	1403 - 11604	ng/L

The results suggest that:

- A lot of the PAH components are transported to the near surroundings as small particles of dustfall, i.e. 100-200 µg PAH/km vehicle day is deposited within 100 m from the highway in the winter period.

- Only a minor part of the PAH components are transported via pavement runoff, i.e. less than 10 g PAH/km vehicle day as a mean for the whole year.

- Approximately equal amounts of inorganic constituents (e.g. lead) are transported to the surrounding area as dustfall and via pavement runoff. Total is approximately 1 mg Pb/km vehicle day transported via runoff and 1 mg Pb/km vehicle day as dustfall. The major part of the dustfall for inorganic components is deposited within 7 m from the highway.

- The major part of the PAH pollution is "produced" in the winter time due to the use of ribbed tires and is deposited as fine particulate dust in the snow along the highway. The snow melting period thus represents a critical time of the year, where relatively large amounts of fine particulate matter containing PAH are transported to water resources together with the melting water.

- The melting period also seems to be the most critical period regarding inorganic constituents. A main portion of pollutants are deposited in the snow in the road ditch, near the highway, and are transported to the sewer system as snowmelt runoff.

3. Investigation of the properties of the surface runoff from Federal Highways in Germany (Stotz, 1987). The Science of the Total Environment 59 (1987) 329-337

Three highway sites were monitored, with ADT range of 40 600 - 47 000. The weighted average pollutant concentrations are compared with those of the local precipitation concentrations in the following table, on page 28.

In order to quantify the properties of highway runoff and the important factors influencing these properties, extensive investigations and water analyses were carried out from samples collected at three federal highways, with heavy traffic, in the years from 1978 to 1981.

Polycyclic aromatic hydrocarbons (PAHs) can be found in the surface water from the federal highways in concentrations that are 50 to 60 times higher than those in the water of rivers and lakes.

Only a small percentage (approximately 14%) of the PAHs can be found in the soluble phase. Thus the major portion of the PAHs can be removed by separating off the solids in the runoff.

For purposes of comparison, the yearly pollution loads resulting from the precipitation of airborne particles and rain are also listed in the table.

When the pollution loads from the three highway sections are compared with each other; then it can be seen that most of the pollutant quantities, with the exception of chloride, were only half as large or even much smaller at the A 8/B 10 measuring point than at the A 6 and A 81 highway sections.

TABLE
YEARLY POLLUTION LOADS

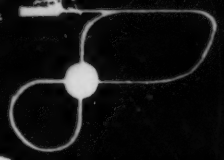
	yearly pollution loads in highway surface run-offs			yearly pollution loads in settled airborne particles and in precipitation		
	A 81 Pleidelsheim	A 6 Obereisesheim	A 8/B 10 Ulm-West	Pleidelsheim	Obereisesheim	Ulm-West
	in kg/(ha.a)			in kg/(ha.a)		
filterable solids	873	848	479	169	283	200
COD	672	557	207	253	236	243
mineral oil	43.27	27.09	4.85	4.94	3.83	2.29
PAH	0.018	0.014	0.005	-	-	-
Cd	0.037	0.029	0.0072	0.013	0.009	0,003
Cr	0,062	0.100	0.012	0,040	0,002	0,015
Cu	0.621	0.544	0.130	0,223	0,125	0.060
Fe	23.37	28.81	4.37	3.60	4.65	1.34
Pb	1.332	1.155	0.360	0.325	0.307	0.179
Zn	2,329	2.892	0.715	1.261	0.907	0.571
Cl^-	1011	777	1344	15.62	2.7	-
NH_4^+-N	4.60	3.22	1.03	11,11	10,57	5,76
P_{tot}	1.62	1.45	0.63	1,04	1,45	0,98
run-off in $m^3/(ha.a)$	6709	4715	2113	-	-	-

Close examination of the data listed in the table reveals that the different pollution loads resulted for the most part from the strongly differing runoff quantities. Fifty-two percent of the drainage at the A 8/B 10 measuring point took place by means of ditches in the unpaved shoulders of the highway; thus the runoff/precipitation ratio was, on an average, only 0.35, as opposed to values of 0.72 and 0.92, respectively for the A 6 and A 81 highway sections. The pollutants in the surface runoff either are carried into the ground by the seeping water or they remain temporarily or permanently in the ditches in the shoulders of the highway (e.g. filterable solids). The surface runoff and the quantity of pollutants reaching the receiving water are thus significantly reduced.

The pollution loads measured in the settled airborne particles and in the rainwater also differed strongly depending on the substance and the measuring point. The pollution loads found in the settled airborne particles and in the rain were much lower in comparison with those found in the highway surface runoff, especially in the case of traffic-specific substances, such as chloride.

4. A comprehensive report on the work done by U.K. Researchers was released by the Transport and Research Laboratory (Colwill, D.M., et al.). The relevant pages of their report are reproduced in the following pages. The literature review report continues on Page 30.

TRRL Supplementary Report 823



TRANSPORT and ROAD RESEARCH LABORATORY

DEPARTMENT of the ENVIRONMENT DEPARTMENT of TRANSPORT

Water quality of motorway runoff

by

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4.2 Water quality

Table 2 presents the range of concentrations in water quality parameters observed during the period November 1980 – October 1981. Some earlier work related to this study has been reported elsewhere[2–4].

4.2.1 Seasonal differences. The quality data for selected parameters (Cl, Br, TS, TVS, TSS, Pb, Zn and Cd) have been compared on a seasonal basis from the arithmetic mean of the flow-weighted mean concentrations for each runoff event (Table 3). The 'winter' and 'summer' periods are as defined in the previous section.

The difference in total solids (TS), total volatile solids (TVS), chloride (Cl) and bromine (Br) concentrations between winter and summer events were statistically significant at the 95 per cent confidence level. The high winter total solids and chloride levels and the generally high range in electrical conductivity were a direct result of de-icing salt application which dominates the material load during winter events. The relative winter to summer concentrations in total solids and chloride is approximately 10:1 and 100:1 respectively.

The mean dissolved solid contribution to total solids is over 90 per cent in winter consisting principally of sodium chloride. Total solids concentrations during this period are therefore dictated almost entirely by the mobilization of dissolved solids and in particular by the frequency and extent of de-icing salt applications. The rapid rate of solubilisation of salt (NaCl) results in peak total solids, chloride and total dissolved solids concentrations during the initial stages of the event. There then follows a gradual decrease through the storm to levels which are generally one or two orders of magnitude lower than the peak, depending on the intensity of the storm. Over 80 per cent of the total solid load released per event occurs within the first 50 per cent of the total runoff volume. For events following de-icing salt application which is normally applied at a rate of 20–40 g/m^2, the chloride and electrical conductivity values rarely fall below 200 mg/l and 800 μS respectively. The complete removal of applied rock salt by a single event occurs when rainfall exceeds 4 mm.

In summer the mean dissolved solid contribution to the total solids is approximately 30 per cent with sodium (Na), calcium (Ca), chloride (Cl) and carbonate (CO_3) as the major contributors to dissolved inorganic material. The length of the antecedent dry period, or the antecedent traffic flow, appear to be closely related to the material available for release. The mobilisation of dissolved material is influenced by a combination of the rate of dissolving and the dilution at higher flow rates. Peak concentrations of total dissolved solids and chloride generally occur during the initial stages of the event and as material is removed from the road surface so levels decrease and the concentration becomes inversely proportional to flow rate. During high intensity events, after the initial flush of dissolved material, chloride and electrical conductivity values tend towards background rainfall levels (Figure 4). Thus dilution at high rainfall intensities helps to disperse and attenuate soluble contaminants and reduces the impact on receiving streams.

Significantly higher levels of bromine than usually occur in surface waters have been found. Detailed studies, previously reported[5], have identified vehicle emissions as a major source of bromine, while seasonal variations have been related to the application of de-icing salt which contains in the region of 230 mg/kg bromine.

The reason for higher total volatile solids levels in winter is not entirely clear. Some effect of dilution in summer or increased degradation of the road surface by salting may be of importance.

Volatile solids consist of carbonaceous material from soil and dust particles, either wind blown or deposited from vehicles, as well as oil, bitumen, tyre rubber and trace levels of the heavier non-volatile fraction of diesel fuel.

TABLE 2

Ranges of concentrations in water quality parameters

Parameter		Winter	Summer
pH Range	max	7.6	7.0
	min	6.1	5.7
	n	(13)	(11)
Electrical	max	22000	552
conductivity	min	80	25
µS	n	(13)	(11)
Total	max	12860	3700
Solids (TS)	min	167	< 15
mg/l	n	(13)	(10)
Total Dissolved	max	12560	455
Solids (TDS)	min	1441	12
mg/l	n	(6)	(6)
Total Volatile	max	940	229
Solids (TVS)	min	56	< 20
mg/l	n	(10)	(10)
Total Suspended	max	717	3430
Solids (TSS)	min	52	18
mg/l	n	(13)	(11)
Oil	max	40	23
	min	8	6
mg/l	n	(9)	(3)
Chemical oxygen	max	362	575
demand (COD)	min	44	36
mg/l	n	(5)	(9)
Chloride (Cl)	max	6714	40
	min	12	1.0
mg/l	n	(13)	(11)
Bromine (Br)	max	6.0	2.3
	min	0.2	0.05
mg/l	n	(13)	(11)
Total Lead (Pb)	max	2874	8015
	min	316	100
µg/l	n	(13)	(9)
Total Zinc (Zn)	max	4047	3425
	min	275	116
µg/l	n	(13)	(9)
Total Cadmium (Cd)	max	102	39
	min	< 3	< 3
µg/l	n	(13)	(5)
Total Copper (Cu)	max	30	
µg/l	min	7	
Total Chromium (Cr)	max	85	
µg/l	min	18	

n = number of events sampled

TABLE 3

Seasonal means for winter and summer periods

	TS† (mg/l)	TVS (mg/l)	TSS (mg/l)	Cl (mg/l)	Br (mg/l)	Pb (µg/l)	Zn (µg/l)	Cd (µg/l)
Winter								
$\bar{x}$	3003	242	169	1551	2.1	630	1130	15.2
RSD	105	71	40	113	60	47	81	67
Summer								
$\bar{x}$	325	98	230	17	0.58	550	1176	11.4
RSD	24	39	73	56	45	49	25	36
Significance levels of differences between means	>95	>95	<90	>95	>95	<90	<90	<90

$\bar{x}$ = Seasonal Mean
RSD = Relative Standard Deviation (%)
† = See Table 2 for key to symbols

Figure 5 shows a typical gas chromatogram of the dichloromethane soluble organic fraction, where the homologous series of alkanes C_7–C_{18} and their relative concentrations are similar to those found in diesel fuel. The hump is characteristic of a mixture of branched chain and aromatic hydrocarbons.

The total volatile solids (TVS) to total solids (TS) ratio is approximately 0.1 and 0.3 in winter and summer respectively. It is estimated that between 50 per cent and 60 per cent of the total volatile solids exist in the soluble form, comprising of natural organic material leached from soil and dust particles as well as soluble oil, which can account for up to 30 per cent of the total oil present.

There is no statistically significant difference in total suspended solids (TSS), lead (Pb), zinc (Zn) and cadmium (Cd) levels between winter and summer event means. In the case of total suspended solids this lack of significance may be partly accounted for by the compensating effects of greater dilution and increased mobilisation at higher flow rates during summer events. Also important is the contribution to winter total suspended solids by de-icing salt, which has about 6 per cent by weight in the form of insoluble particulate material. The majority of these solids (80 per by weight) consist of grit-like particles (1–3 mm diameter) which will not be mobilised except at high flow rates. The remaining 20 per cent consist of a fine, clay-like material which is easily mobilised by low intensity events. It is estimated that salting contributes up to 25 per cent to the total suspended solids recorded in winter.

Suspended solid concentrations are markedly increased at high flow rates as scouring of the road surface takes effect. The overall characteristic of rainfall and runoff of an event is considered to be the dominant factor in determining the concentration of suspended solids and the load discharged. There is little evidence to suggest that, in the absence of de-icing salt application, the antecedent dry period is a significant factor in determining suspended solids loads from this catchment. This is not altogether surprising in view of the exposed nature of the site. Traffic generated turbulence will serve to significantly disperse deposited dust and particulate matter away from the road surface and equilibrium conditions between rate of deposition and rate of removal can be expected to be reached within a relatively short period of time after an event.

As particulate material mobilisation is dependent on flow velocities, the first flush phenomenon is not a common feature of all storms but is related to the character of the rainfall–runoff event. Thus, although high suspended solid levels are normally encountered during the initial stages of the event, peak levels generally coincide with either peak flow rate or peak rainfall intensity. The magnitude of the peak suspended solid concentrations is also closely related to the magnitude of the peak flow rate and it is evident that a critical flow velocity or rainfall intensity has to be reached during the initial stages of an event for the first flush phenomenon to be realised (Figure 4). During prolonged low intensity events with flows less than 0.2–0.3 l/sec (0.9–1.4 mm/h) suspended solid levels rarely exceed 200 mg/l and the concentration remains fairly uniform throughout the event.

The first flush phenomenon is a more frequent feature during summer when events with short rise times (steep rising limb) and peak flows in excess of 1 l/sec (4.5 mm/h) produce a high initial suspended solid load and concentrations during this phase commonly exceed 1000 mg/l. Levels decrease sharply during the receding limb of the hydrograph but rarely fall below 50 mg/l.

4.2.2 Chemical oxygen demand. As both soluble and particulate material contribute to chemical oxygen demand (COD) there is no clear relationship between this parameter and total dissolved solids or total suspended solids. Chemical oxygen demand generally shows a first flush effect where concentrations can exceed 500 mg/l but falls off gradually to between 25 per cent and 50 per cent of the peak initial concentration. Results indicate that chemical oxygen demand is principally attributable to dissolved solids and that the contribution from particulate material becomes important only during high intensity events, when suspended solid levels are high.

4.2.3 Oil and polynuclear aromatic hydrocarbons. The organic content of volatile suspended solids ranges between 20 and 40 per cent with oil accounting for an estimated 20 to 50 per cent of this volatile fraction. The oil content of sediments varies with particle size and is influenced by seasonal factors such as the road surface temperature and the antecedent dry period. In summer, levels generally range between 50 mg/g and 100 mg/g of solid although values in excess of 300 mg/g have been recorded. Sediments of size range 200 μm to 400 μm generally contain the highest oil levels.

The oil fraction found at low initial flows is dependent on the traffic flow during the antecedent dry period. A higher soluble proportion is found after shorter dry periods, presumably because association with solid material and oxidation have not taken place. Thus, on average, 70 per cent of the oil is solid associated with higher proportions being found after long dry periods. Total oil levels generally range between 5 and 30 mg/l though concentrations in excess of 100 mg/l have been recorded specifically during high intensity events when suspended solids levels are high.

Polynuclear aromatic hydrocarbon (PAH) levels are very closely related to oil concentrations and are predominantly solid associated with the soluble fraction usually accounting for less than 15 per cent of the total. The polynuclear aromatic hydrocarbon content of road dust and runoff sediments is presented in Table 4. Total PAH concentrations range from 0.15 μg/l showing a definite first flush with initial concentrations being about twice the mean storm level. The PAH content of the oil fraction is fairly constant at 0.1–0.5 g/kg of oil which compares closely with the PAH level found in used vehicle engine oil (0.11 g/kg). Benzo(a)pyrene generally accounts for 20 per cent by weight of the six polynuclear aromatic hydrocarbons included in the World Health Organisation standard for water quality.

4.2.4 Metals. The range of concentration of the principal non-ferrous metals present in runoff are presented in Table 1. Total metal levels, including soluble and solid associated fractions are dictated largely by zinc and lead and can often exceed 2000 μg/l, particularly for events which show a pronounced first flush.

TABLE 4

PAH levels on road dust and runoff sediments

PAH	Road Dust (μg/g)	%	Runoff Sediment (μg/g)	%
F	2.5	29	9.3	32
B(b)F	2.2	26	6.2	22
B(a)P	1.7	20	5.4	19
B(ghi)P	1.2	14	4.2	14
B(k)F	0.5	6	2.1	7
IP	0.4	5	1.7	6
Total PAH	8.5		28.9	

F – Fluoranthene; B(b)F – Benzo(b)fluoranthene; B(a)P – Benzo(a)pyrene; B(ghi)P – Benzo(ghi) perylene; B(k)F – Benzo(k)fluoranthene; IP – Indeno(123cd)pyrene.

The mechanism of removal of metals from the road surface is dependent, in addition to storm characteristics, on metal speciation at the time of discharge, variation in pH throughout the storm and, to some extent, on the size distribution of the sediment fraction.

The mobilisation of metals which are predominantly solid associated, such as lead, is flow rate dependent, whereas those which are readily dissolved, such as cadmium, result in peak concentrations during the initial stages of the event.

The behaviour of zinc is complicated by the widely fluctuating percentage solid associated levels which can range between 20 and 80 per cent of the total zinc concentrations. Soluble zinc remains fairly constant throughout the event ranging between 100 and 300 μg/l although levels in excess of 1000 μg/l have been recorded on several occasions. There is a substantial variation in the solid associated fraction from 50 to 3000 μg/l with sediments normally containing between 0.5 and 2 μg of zinc per gram of solids.

Within the pH range normally encountered in motorway runoff, lead is only weakly dissociated and it is generally found that over 90 per cent of the total lead concentrations is solid associated with the soluble fraction rarely exceeding 20 μg/l. Peak lead levels therefore coincide with maximum suspended solids concentrations and the correlation coefficient between them is generally greater than 0.9. Solid associated lead levels in runoff samples range between 1 and 6 mg/g of solid. Analysis of sieve solids and particles collected from the road surface show a clear trend towards higher lead levels with decreasing particle size (see Table 5). The effect of this size dependence results in low lead/total suspended solids ratios during high flows as larger particles are more easily mobilised and very high ratios during low flows. The very high ratios (> 5 mg/g) encountered during low flows is probably caused by the deposition of fresh vehicle particulate emissions during the storm.

4.2.5 In-storm traffic. The influence of in-storm vehicle traffic on runoff quality cannot be readily assessed as traffic flow remains fairly constant at 1000 to 4000 vehicles per hour during most of the day and only falls to around 200 vehicles per hour between 0000 hours and 0500 hours. The effect of the variation in traffic flow during the day is overshadowed by other more dominant factors such as the storm characteristic and the antecedent dry period. However a general trend to lower mean suspended solid levels for events which occur in the early hours of the morning is evident compared with similar events during heavily-trafficked periods.

TABLE 5

Lead content of road dust and runoff sediments

Solid Size Fraction (μm)	Road Dust (mg/g)	Runoff Sediment (mg/g)
1600–500	1.45	–
500–250	1.56	0.79
250–150	1.8	1.59
150–125	2.29	1.84
125–63	2.66	2.31
63–38	2.21	2.41
<38	2.76	2.95

4.2.6 Material loads. The annual yields of material per kilometre of motorway presented in Table 6 have been calculated from the flow weighted mean concentrations and on the basis of 500 mm runoff per year. The estimated material loads for this catchment are in general agreement with other water quality studies of motorway runoff (Table 7).

TABLE 6

Material loads (kg/km year)*

Total solids	(TS) (no salting)	2400
Total suspended solids	(TSS)	1500
Total volatile solids	(TVS)	740
Lead	(Pb)	4
Zinc	(Zn)	8
Oil	(Oil)	126
Polynuclear aromatic hydrocarbons	(PAH)	18×10^{-3}

* Based upon 500 mm runoff per year

4.2.7 Spray and atmospheric deposition. The results from the rainfall collector grid show no clear pattern in total rainfall volume with distance from the motorway nor any appreciable spray effects as all were within ±10 per cent of the volume collected at the 600 m control site. On several occasions however, the gauges furthest from the motorway (4.5 m) contained the largest volume indicating a pronounced vehicle generated turbulence effect.

Analysis of rainfall data from 23 events established that spray losses can only account for less than 10 per cent of total rainfall and that any variation with distance is within the standard error of rainfall measurement of ±0.34 mm for the tipping bucket rain gauges used.

A further estimation of total losses was carried out by comparing rainfall and runoff hydrograph volumes The total losses computed in this way ranged from 0.25 mm to 0.75 mm water depth which is within the range of the calculated surface wetting storage of between 0.49 mm and 0.97 mm for this type of road surface.

TABLE 7

Comparison of mass loads for motorway runoff for impermeable surfacings (kg/ha/mm runoff)

Parameter	United Kingdom (This Study) M1	United Kingdom Birmingham M6 (6)	Switzerland Zurich N1 (7)	United States* (8)	France† A1/A2 (9)
TSS+	2.0	11.8	1.1	2.6	1.3
TVS	1.0	–	–	2.4	–
Pb ($x10^{-3}$)	5.9	24	3.5	9.7	2.4
Zn ($x10^{-3}$)	11.5	36	2.7	4	3.8
Oil	0.17	–	–	–	–
PAH ($x10^{-3}$)	0.025	–	–	–	–

* mean value from six monitoring sites
† estimated upper limits
+ see Table 6 for key to symbols

It is therefore considered unlikely that vehicle generated spray constitutes a significant loss to surface runoff. Losses result principally from surface wetting and storage in depressions and, at most, spray effects accounts for 10 per cent of total rainfall.

The water quality of rainfall collected in the vicinity of the motorway is comparable and often considerably worse than road surface runoff itself (Table 8). As spray effects are not important, much of this material consists of road surface deposits distributed on the gauges by vehicle generated turbulence during dry periods.

The rate of aerial deposition of particulate material within 1 m of the hard shoulder is twenty times greater than background. Table 9 illustrates this point and shows that the rate of deposition falls of rapidly with distance.

It is estimated that the airborne dispersal of dust and particulate matter away from the road surface by traffic generated turbulence disperses 630 kg/km year of insoluble solids, 57 kg/km year of oil and 2 g/km year of polynuclear aromatic hydrocarbons within a distance of about 5 m from the hard shoulder of the motorway. Comparing these levels with loads removed by runoff (Table 6) it is apparent that this is an important pathway for the removal of material from the carriageway and that the effect of the antecedent dry period on runoff quality is influenced largely by the equilibrium conditions reached between the rate of deposition and the rate of removal as vehicles redistribute material to adjacent land.

5. CONCLUSIONS

These conclusions are drawn from a study near a heavily trafficked rural motorway and information is not available, at present, to support extrapolation of the inferences to other sites.

1. Salt, used for de-icing the road surface, is the most concentrated contaminant in runoff during winter.

2. The concentrations of other soluble pollutants in runoff are dependent on the length of the dry period before the storm and the traffic flow during that period. The highest concentrations of these pollutants occur in the initial runoff and then concentrations fall rapidly.

3. The concentration of suspended solids and the total load released by individual events are influenced principally by rainfall intensity and the total volume discharged. The highest concentration of particulate material and associated contaminants generally coincide with peak rainfall intensity or peak flow rate.

4. The total annual yields of suspended solids, lead, oil and polynuclear aromatic hydrocarbons are estimated to be 1500, 4, 126 kg/km and 18 g/km respectively. .

5. Water losses by spray from vehicles accounts for not more than 10 per cent of total rainfall.

6. The airborne dispersal of material from the road surface by vehicle generated turbulence during dry periods is an important pathway for the removal of material from the carriageway. The rate of deposition of pollutants on land adjacent to the motorway falls off rapidly with distance.

6. FURTHER WORK

Work is in progress at the experimental catchment used in this study to assess the effect of different drainage/ treatment systems (french drains, sedimentation tanks and open retention ditches) on road-surface runoff quality.

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8. REFERENCES

1. DEPARTMENT OF THE ENVIRONMENT (1972). The analysis of raw, potable and waste waters. H M Stationery Office, London.

2. POPE, W, N J D GRAHAM, R J YOUNG, R PERRY. (1978) Urban runoff from a road surface – a water quality study. Prog. Water. Tech., 10, 533–543.

3. POPE, W, R J YOUNG, R PERRY. (1978) Correlations of hydrological conditions with water quality in motorway runoff. OECD Symposium on Road Drainage, Berne, 384–400.

4. POPE, W, R J YOUNG, C J SOLLARS, R PERRY. (1979) The distribution of selected heavy metals in a motorway environment. Proc. Int. Conf. on Heavy Metals in the Environment, London, 230–235.

5. SOLLARS, C J, C J PETERS, R PERRY. (1982) Bromide in urban runoff-water quality considerations. Proceedings of the IAHS Exeter Symposium.

6. HEDLEY, G, J C LOCKLEY. (1975) Quality of water discharged from an urban motorway. Wat. Pollut. Control, 74, 659–674.

7. DAUBER, L, B NOVAK, J ZOBRIST, F ZURCHER. (1978) Pollutants in motorway stormwater runoff. OECD Symposium on Road Drainage, Berne, 332–342.

8. FEDERAL HIGHWAY ADMINISTRATION (1981) Characteristics of highway runoff from operating highways, Vol. IV, US PB81241937.

9. CATHELAIN, H, G FRIANT, J L OLIE. (1981) Les eaux de reuissellement de chaussées autoroutières: evaluation des charges de pollution. Bulletin de Liason des Laboratoires des Ponts et Chaussées. No. 116, 9–24.

Another U.K. publication reviewed (Harwood, E., 1986), presents a summary table (Table 3.1) which compares the water quality in precipitation, road runoff, urban runoff and combined sewer overflow. The table is reproduced and can be found on the following page. As expected, highway and general urban runoff generated similar range of pollutant concentration.

Hedley, G. and Lockley, J.C. (1975), in their monitoring of the Ashton (Birmingham) Motorway provided detailed data on the monthly variation of pollutant concentration and loading. Table 1 from their report is enclosed, following the Harwood Table.

Table 3.1
Summary of available information on runoff quality

Determinand	Reported concentration range (mg/l)†			
	Precipitation	Road/street runoff	Urban runoff	Combined sewer overflow
COD	2.5–322	5–1058	5–3100	93–2636
BOD	1.1	25–165	1–700	15–685
Total solids	18–24	145–21 640	400–15 322	150–2300
Volatile total solids	—	37–1500	12–1600	—
Suspended solids	2–13	11–5500	2–11 300	20–1700
Volatile suspended solids	6–16	100–1500	12–1268	113
Settleable solids	—	—	0.5–5400	—
Total dissolved solids	—	66–3050	9–574	—
Conductance (μmho/cm)	8–395	10 000	5.5–20 000	—
Turbidity (JTU)	4–7	—	3–70	—
Colour (Pt–Co units)	5–10	—	5–160	—
Total organic carbon	1–18	5.3–49	14–120	—
Total inorganic carbon	0–2.8	—	1–17	—
Oils/hydrocarbons	—	28–400	0–110	—
Phenols	—	—	0–10	—
Total nitrogen N	0.5–9.9	0.18–14	1.1–6.2	4.0–63.3
Organic N	0.1–0.32	0.18–3.23	0.1–16	1.5–33.1
Inorganic N	0.69	—	1.0–7.60	—
Ammonia N	0.01–0.4	1–2	0.1–14.0	0.1–12.5
Nitrate N	0.02–5.0	0.31–2.62	0.1–6.9	—
Nitrite N	0.01	—	0–4	—
Total phosphorus	0.001–0.35	0.3–3.5	0.09–4.4	1.0–26.5
Hydrolysable phosphorus	0.8–0.24	—	0.1–10	—
Aldrin	—	—	'trace'	—
Dieldrin	0.003¶	6.8×10^{-4}‡	'trace'	—
p,p'-DDD	—	18.9×10^{-4}‡	—	—
p,p'-DDT	—	17.2×10^{-4}‡	—	—
Heptachlor	0.04¶	—	'trace'	—
Lindane	—	—	'trace'	—
PCB	—	311×10^{-4}	—	—
Bromide	—	0.02–6	5	—
Chloride	0.1–1.1	4–700 000	2–25 000	—
Cadmium	0.013–0.056	0.002–0.4	0.006–0.045	—
Chromium	0.023–0.08	0.018–1.0	0.01–27.0	—
Copper	0.06–0.48	0.007–2.5	0.041–0.45	—
Iron	0–3.05	5–440	0–5.3	—
Lead	0.024–10.4	0.01–113	0.01–14.5	—
Mercury	—	0.001–0.07	—	—
Nickel	—	0.02–1.5	—	—
Zinc	0.02–4.9	1–15	0.01–5.23	—
Total coliform (per ml)	—	<1–79 000	240–991 000	—
Total coliform (organisms per km)	—	15.9×10^{10}	—	—
Faecal coliform (per ml)	—	<1–3000	5500–11 200	—
Faecal coliform (organisms per km)	—	0.9×10^{10}	—	—
Faecal streptococcus (per ml)	—	<1–35 000	120–20 000	—

†Unless otherwise indicated units are mg/l.
‡kg/km kerb
¶mg/kg

storms and fewer long-lasting events with steady, low-intensity rainfall. For the data presented, however, only the differences between winter and summer mean peak flows, average mean flows and average peak:mean

TABLE 1. QUALITY OF RUN-OFF FROM ASTON EXPRESSWAY EXPRESSED AS TOTAL LOADING PER MONTH

Months	Rainfall at Spring Lane (mm)	Volume from study area (m^3)	Total SS	Volatile SS	Non-volatile SS	Chlorion	BOD	Total metals	Soluble metals	Total Zn	Total Pb	Total Cu	Total Ni	Total Cr	Total Fe	
July	81·1	2923	160	33·5%**	66·5%**	16	10·3	1·39	0·53	0·65	0·56	0·1	—	—	8·5	Average mg l
			467	156**	311**	47	30	4·1	1·6	1·9	1·6	0·3	—	—	23	Loading kg
August ..	23·0	829	134	35·0%**	65·0%**	27	11·2	1·40	0·74	0·68	0·45	0·1	—	—	8·5	Average mg l
			111	30**	72**	22	9	1·2	0·6	0·6	0·4	0·1	—	0·1	7	Loading kg
September ..	38·8	1398	510	35·5%	63·6%	21	17·0	4·18	0·78	1·91	1·52	0·69	—	—	23·9	Average mg l
			712	260	452	29	24	5·8	1·1	2·7	2·1	1·0	—	0·1	33	Loading kg
October ..	38·7	1395	754	31·5%	68·5%	99	27·4	5·63	1·40	2·70	2·21	0·38	—	—	28·8	Average mg l
			1051	331	720	138	38	7·9	2·0	3·8	3·1	0·8	—	0·1	40	Loading kg
November ..	48·9	1762	547	26·5%	73·5%	341	4·0	8·03	3·45	5·43	1·83	0·45	—	—	39·8	Average mg l
			964	255	709	602	7	14·2	6·1	9·6	3·2	0·8	—	0·5	70	Loading kg
December ..	29·0	1045	2238	17·5%	82·5%	23 674	64 ‡	15·01	6·24	8·01	4·84	1·32	—	—	118·8	Average mg l
			2339	412	1927	24 740	66 ‡	15·7	6·5	8·4	5·1	1·4	1·6	0·3	124	Loading kg
January ..	102·0	3676	2599	24·7%	75·3%	3441	64·5	13·4	1·83	6·59	4·94	1·44	—	—	182·9	Average mg l
			9553	2359	7194	12 647	237	49·3	6·7	24·2	18·2	5·3	1·2	1·0	672	Loading kg
February ..	64·2	2315	1646	22·2%	77·8%	529	49 ‡	6·8	1·38	3·22	2·51	0·81	—	—	74·2	Average mg l
			3811	846	2965	1224	113 ‡	15·7	3·2	7·5	5·8	1·9	0·5	0·2	172	Loading kg
March ..	26·9	969										—	—	—		
			1140 θ	282 θ	858 θ	2104 θ	31 ‡	6·7 θ	1·6 θ	3·4 θ	2·3 θ	—	—	—	64 θ	Loading kg
April	9·1	328	570	31·2%	68·6%	195	33·0	3·4	1·05	1·45	0·8	0·6	—	—	33·0	Average mg l
			187	58	129	64	11	1·1	0·4	0·5	0·3	0·2	—	0·03	11	Loading kg
May	32·5	1171	1204	26·4%	73·6%	77	38 ‡	4·29	0·55	2·1	1·40	0·6	—	—	22·5	Average mg l
			1410	372	1038	90	45 ‡	5·0	0·6	2·5	1·6	0·7	—	0·2	26	Loading kg
June	39·2	1413	632·7	25·6%	74·4%	95	6·2	5·14	0·66	2·37	1·87	0·75	—	—	21·2	Average mg l
			894	230	664	134	9	7·3	0·9	3·4	2·6	1·1	0·3	0·2	30	Loading kg
Total	533·4	19 224	22 639	5600	17 039	41 841	620	134·0	31·3	68·5	46·3	13·6	3·6	2·7	1272	Loading kg

* *Based on hand samples as most reliable estimate.*

‡ *BOD figures based on relation between BOD SS.*

** *Based on monthly figures outside this study period.*

θ *Estimated load calculated from monthly rainfalls.*

A.2 HIGHWAY SURFACE POLLUTANTS

The following literature review is somewhat related to the main topic of highway runoff quality. It contains information on surface pollutants collected by sweeping and in some cases by flushing, but not from monitoring runoff.

Again, the main source of information is the work done by Kobriger, N.P. and Geinepolus A., in 1984, for the U.S. Federal Highway Administration titled Sources and Migration of Highway Runoff Pollutants.

From a series of tests, information became available not just on concentration and loading, but also on the distribution of pollutants across the different lanes.

To characterize highway surface pollutants, sweeping and flushing studies were performed at the same four sites described in Chapter A.1, to estimate the pollutant composition and load.

The wide ranging data base is summarized in Table 2.1. Observed values are expressed in kg per km for each lane. Gross material refers to items large enough to be picked up by hand. Litter is defined as particles larger than 3.35 mm, total solids are particles smaller than 3.35 mm.

Milwaukee surface constituents were the highest, where the ADT was 116,000 vehicles per day. This test site is in an urban centre and had the highest ADT among the four sites tested.

The lowest surface constituents were at the Harrisburg site, which is located in a rural area, with an ADT of 27,800.

TABLE 2.1
SURFACE LOADINGS PER LANE - kg/km

Parameter	URBAN		RURAL SITE	
	Milwaukee Mean	Sacramento Mean	Harrisburg Mean	Efland Mean
Gross material	23.5	-	3.78	15.8
Litter	143	8.6	0.26	284
TS	637	12	3.56	39.8
TVS	49	0.9	0.88	2.9
TOC	8	0.3	0.26	0.30
COD	36	1.2	0.57	1.0
Pb	2.2	0.05	0.0030	0.04
Zn	0.6	0.008	0.0034	0.014
Fe	42.2	0.43	0.03	0.86
Cr	0.06	0.004	0.0002	0.0009
Cu	0.23	0.001	0.00056	0.0024
Cd	0.004	0.00003	0.00056	0.0001
Ni	0.05	0.0007	0.00056	0.0007
As	0.0005	0.00007	ND	ND
Hg x 10^{-3}	0.01	0.0007	ND	ND
NO_2 + NO_3	0.006	0.004	0.016	0.0034
TKN	0.3	0.018	0.02	0.054
PO_4-P	0.19	0.007	0.0016	0.026
Ca	68	0.13	0.23	0.028
Na	1.3	0.018	0.05	0.035
Cl	0.89	0.03	0.112	0.048
SO_4	0.34	0.079	0.184	0.054
Oil, Grease	5.88	0.061	0.082	0.04
Rubber	7.25	1.51	0.096	0.088

Note:

Milwaukee, eight lanes, ADT 116,000
Sacramento, eight lanes, ADT 85,900
Harrisburg, four lanes, ADT 27,800
Efland, four lanes, ADT 25,000

Solids and pollutants associated with solids tend to accommodate in the emergency and median lanes. This tendency is caused by vehicular turbulence. Pollutants which are more soluble are more uniformly distributed across the lanes.

The effect of traffic density on the lead, nickel, cadmium and zinc concentration found in sediments is reproduced on the enclosed figure taken from Kobriger et al. (1984). It clearly shows the effect of ADT on pollutant concentration. Although the graph describes pollutants associated with sediments, it is safe to assume that the ADT values similarly influence the runoff water quality.

Distribution of pollutant load across the paved highway surface taken at Milwaukee, Sacramento, Harrisburg and Efland showed that the majority of the loading comes from emergency and median lanes and not from the travel lanes. (Table 2.2 reproduced from Kobriger, N.P., and Geinopolos, A. (1984)).

GM barrier positioned at the median lane effectively traps and/or re-entrains most of the particles which accumulate in the median section. Approximately 90% of the median lane pollutant load was located within the first 2 feet distance from the GM barrier.

Mass balance calculations were presented by Kobriger, N.P., and Geinopolos, A., (1984). The mass balance monitoring was based on particles under 250 micron in size. This is the size group mostly associated with the major removal mechanisms, such as runoff and atmospheric deposition. Results of the Milwaukee test site are shown on Table 2.3.

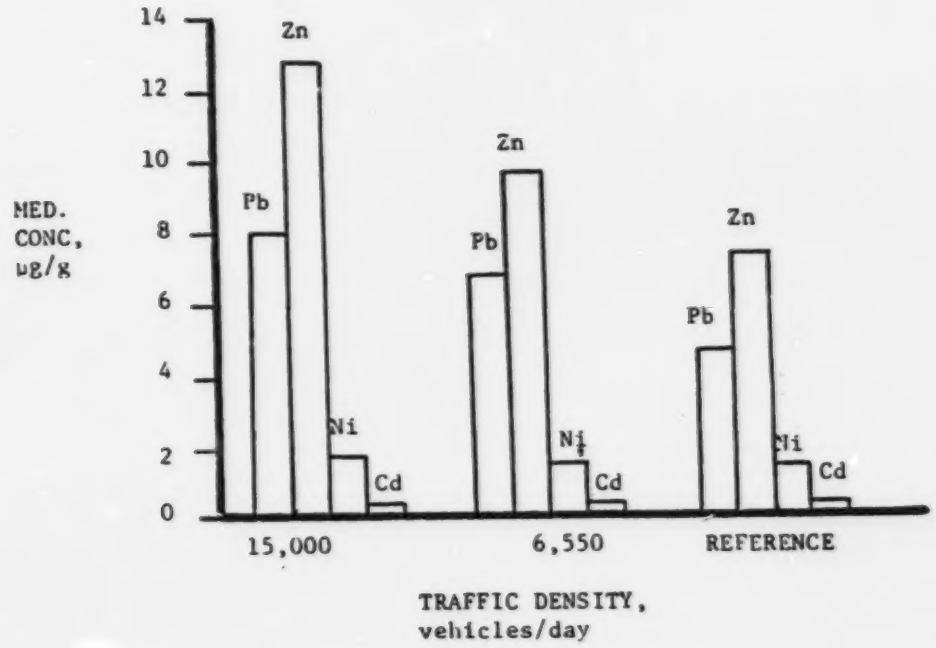


Figure 33. Median concentration of lead, nickel, cadmium, and zinc in sediments at each area over a 1-year period.

TABLE 2.2

DISTRIBUTION OF POLLUTANT LOAD ON PAVED HIGHWAY SURFACE - PERCENT

Parameter	Milwaukee Emergency and Median	Sacramento Emergency and Median	Harrisburg Emergency	Efland Emergency and Median
Gross Material	100	100	100	100
Litter	100	100	100	100
TS	98	87	56	98
VTS	93	70	53	91
TOC	83	77	54	45
COD	88	73	80	48
Pb	99	96	66	96
Zn	98	87	50	90
Fe	99	95	80	99
Cu	96	82	50	89
Cr	96	96	48	93
Cd	97	100	25	83
Ni	92	81	26	91
Hg (10^{-3})	91	27	-	-
As	100	92	-	-
TKN	75	57	42	86
NO_2+NO_3	31	54	32	29
TPO_4	98	85	42	96
SO_4	61	32	29	23
Ca	-	41	33	48
Na	93	41	27	42
Cl	63	36	39	42
Oil, Grease	98	62	45	68
Rubber	99	91	53	49

TABLE 2.3
MILWAUKEE SITE
MASS BALANCE OF TS - kg/km PER LANE

	17 April - 31 October		1 November - 4 May	
Initial Load	124		19	
Deposition				
Vehicle	899	87%	2 968	30%
Rainfall	86	8%	} 113	1%
Dustfall	43	5%		
De-icing	-	-	4 569	60%
Total	1028	100%	7 650	100%
Removal				
Runoff and base flow	662	58%	3 931	76%
Atmospheric	278	25%	421	8%
Sweeping	193	17%	848	16%
Total Removal	1133	100%	5 200	100%
Remaining	19		2 469	

A.3 SOURCES AND MIGRATION OF HIGHWAY POLLUTANTS

To better understand the make-up of the water quality in highway runoff, a brief literature survey was carried out on information listing sources of highway pollutants.

The following pages list:

- Rainfall
- Dry precipitation
- Exhaust
- Vehicles
- Metals
- De-icing agents

Migration of highway pollutants are caused by wind and turbulence caused by vehicles.

A.3.1 Sources of Highway Pollutants

i) Rainfall (precipitation)

Detailed monitoring on precipitation quality at four sites in the U.S. (see Chapter A.1) provide the best data on pollutant concentration and loading contained in precipitation (Kobriger, N.P. and Geinopolos, A., 1984).

The four sites had different climatic, land use and highway design and traffic characteristics.

By far, the most urbanized monitoring area was in Milwaukee, containing also industrial area, as the adjacent land use.

The Sacramento site is bounded by residential areas including several parks.

The Harrisburg and Efland sites are located in a rural area.

Results of the sampling of precipitation quality over the 1978-1982 period at the four sites were analyzed and are summarized in the following pages (Table 3.1).

It is clear from the results that precipitation in urban areas contain higher median values and higher range of individual samples of parameters than the rural areas.

Generally, no seasonal variation was detected in the data, except for chlorides. The individual samples at Milwaukee showed a trend in higher chloride contents during the winter months, as shown in Table 3.2.

TABLE 3.2
MONTHLY CHLORIDE CONCENTRATIONS

Month	Cl - mg/L
January	10, 27, 25, 7
February	9
March	10
April	2, 9.5
May	10
June	ND
July	ND
August	2
September	-
October	1.4
November	10
December	-

The higher January values are attributed to de-icing activity.

TABLE 3.1
SUMMARY OF PRECIPITATION QUALITY AT URBAN AND RURAL HIGHWAYS
(mg/L)

Parameter	URBAN SITES Median Values		Range	RURAL SITES Median Values		Range
	Milwaukee	Sacramento		Harrisburg	Eflanu	
pH	3.8	5.0	2.7 - 6.8	4.3	4.2	3.2 - 5.6
TS	44	64	16 - 210	30	12	2 - 68
TVS	19	13	6 - 70	12	7	ND - 48
SS	12	4	2 - 55	5	1	ND - 30
VSS	5	1	ND - 12	2	ND	ND - 5
TOC	8	11	ND - 26	5	11	ND - 19
COD	23	11	8 - 45	ND	13	ND - 17
Pb	ND	ND	ND - 0.3	0.02	ND	ND - 0.2
Zn	0.17	0.11	ND - 3.9	0.08	0.03	ND - 0.29
Fe	0.20	0.18	ND - 1.0	0.30	0.08	0.05 - 1.50
Cu	ND	ND	ND - 0.04	ND	0.002	ND - 0.11
Cr	0.04	0.035	ND - 0.71	0.04	0.03	0.01 - 0.16
Cd	ND	0.008	ND - 0.04	ND	ND	ND - 0.04
Ni	ND	0.05	ND - 0.2	ND	ND	ND - 0.2
As, Hg	ND	ND	ND	ND	ND	ND
NO_2 + NO_3	0.79	0.16	0.07 - 1.96	0.2	0.19	0.03 - 1.81
TKN	2	1.1	ND - 3.2	0.64	0.84	ND - 2.0
PO_4 - P	0.05	ND	ND - 0.14	ND	ND	ND - 0.04
Sulphate	3	ND	ND - 12	ND	ND	ND - 13
Na	1.25	2.0	0.3 - 14	0.2	0.23	ND - 2.0
Cl	9	3	ND - 27	1	3	ND - 6
PCB x 10^{-3}	0.05	0.31	ND - 0.31	0.2	ND	ND - 0.26
Oil & Grease	ND	-	-	ND	ND	ND
Precipitation - mm	6.4	29	2.5 - 37.3	13.7	29.2	2.5 - 94

ND - Not detectable

ii) Rainfall and Dustfall

Bulk data, Table 3.3 which includes wet and dry deposition showed even greater differences between urban and rural sites than precipitation alone presented in Table 3.1.

TABLE 3.3
SUMMARY OF WET AND DRY PRECIPITATION LOADINGS
mg/m² PER DAY

	URBAN SITES			RURAL SITES		
Parameter	Milwaukee Median	Sacramento Median	Range	Harrisburg Median	Efland Median	Range
TPM	130	160	20 - 890	30	40.3	8.6 - 103
Pb	0.057	0.245	0.008 - 1.0	ND	0.006	ND - 0.063
Zn	0.258	0.023	0.009 - 0.042	0.015	0.007	0.00004 - 0.026
Fe	1.86	2.59	0.327 - 4.7	0.382	0.424	0.024 - 0.672
Cr	0.005	0.033	0.001 - 0.12	0.002	0.002	0.00002 - 0.002
Cd	ND	ND	ND - 0.11	ND	ND	ND - 0.001
Ni	0.008	0.004	ND - 0.663	ND	ND	ND - 0.002

ND - Not Detectable

Wet and dry precipitation recorded in the U.K. (Colwill, D.M. et al. 1984), showed a decreasing concentration when measured 1, 2 or 3 m from the highway (see enclosed Tables 8, 9 copied from that report).

TABLE 8

Rainwater quality (total wet and dry gauges)

Parameter	Distance from Carriageway 1 m	2 m	3 m
pH	6.1	5.8	5.7
Electrical Conductivity (μS)	712	237	188
Total Dissolved Solids (TDS) (mg/l)	713	630	439
(inorganic)	(557)	(270)	(233)
(organic)	(156)	(360)	(206)
Total Suspended Solids (TSS) (mg/l)	557	156	185
(inorganic)	(318)	(89)	(113)
(organic)	(188)	(67)	(72)
Total Oil (mg/l)	52	47	36
Soluble Oil (mg/l)	15	30	20
Total Polynuclear aromatic hydrocarbons (PAH) (μg/l)	2	1	1
Soluble PAH (μg/l)	0.4	0.2	0.1

TABLE 9

Atmospheric deposition rates (mg/m^2 day)

Pollutant	Distance from hard shoulder (m) 0.5	2.5	4.5	600
Total Suspended Solids (TSS)	1000	360	190	40
Lead (Pb)	4	1.8	1.5	0.03

iii) Vehicle-Related Deposition (Kobriger, N.P. and Geinopolos, A.), 1984

Particulates of vehicular origin are:

37% tire wear
37% pavement wear
18.5% engine and brake wear
7.5% settleable exhaust

iv) Exhaust Related Deposition

- Unleaded fuel cars exhaust = 0.103 kg/1000 vehicle - km of suspended particulates.

- Leaded fuels = 0.094 kg/1000 vehicles - km. Lead was less than 1/3 of total particulates, while carbon compound was another 35%.

- Carbon emissions represent 20% of the total particulates for unleaded fuel cars.

- Other tests showed 0.065 kg/1000 vehicle - km, consisted of 45% lead.

v) Dustfall

- Dustfall measurements taken across the U.S. ranged 17-76 kg/ha per month.

vi) Lead

- Average deposition rate of 0.0049 g/vehicle - km. Most of it in inorganic form. Most of the lead in the exhaust is less than 0.5 micrometers in size.

vii) Zinc

- From tire wear above the average deposition rate is 0.003 g/vehicle-km.

viii) Iron

- Mainly from autobody rust, steel highway structures, engine parts.

ix) De-icing Agents

Rock salt (NaCl) and liquid calcium chloride ($CaCl_2$) used as deicing agents were tested to estimate metal concentration.

Sodium chloride applied 71,000 kg/km during two winter periods contained the following loads (kg) per km.

Pb	0.45
Zn	0.11
Cr	0.07
Cu	0.22
Cd	0.07
N	0.45
CN	1.56

Cyanide in rock salt, 0.79 kg/km per year.

x) Rubber: The average wear is 0.36 - 0.41 g/vehicle - km.

xi) Asbestos

Average asbestos loadings on highways resulting from brake and clutch-wear are estimated as follows (Kobriger, N.P., and Geinepolos, A., (1984).

Passenger cars	45.9 µg/km
Light trucks	141 µg/km
Medium trucks	468 µg/km
Heavy trucks	1530 µg/km

Samples of ambient air, roadway debris, precipitation, runoff and dustfall were taken at an exit ramp near a FHWA study site. Despite significant braking and clutching, no asbestifoam material was found above detectable limits in the samples.

xii) Total Particulate Matter (TPM)

Deposition adjacent to highway monitoring areas was used to determine the quantity of TPM transported from the paved highway surface to areas adjacent to the highway, through the atmosphere by blow-off, due to wind and vehicular turbulence (Kobriger, N.P. and Geinopolos, A., 1984).

Atmospheric deposition of total particulate matter drops sharply within the first 10 m from the edge of pavement and approaches background level 30-40 m from edge of pavement. Similar results are obtained from snow samples taken along the highway (Table 3.4).

Metals associated with bulk precipitation follow the same pattern.

The same applies to the top 1 cm of soil near the highway.

TABLE 3.4

CONCENTRATION CHANGES IN SNOW ON THE GROUND - (mg/L)

Parameter	Distance From Edge of the Pavement - m			
	0.5	15	35	140
pH	7.4	6.9	6.8	5.2
TS	3660	295	199	97
TVS	259	28	41	26
SS	810	53	85	34
VSS	218	16	13	9
Pb	3.9	0.4	0.5	0.2
Zn	1.6	0.7	0.26	0.15
Fe	35	4.9	4.5	2.2
Cr	0.14	0.02	0.03	ND
Cu	0.64	0.19	0.11	0.07
Cd	0.02	0.09	ND	ND
Ni	ND	0.2	ND	ND
Hg	ND	ND	ND	ND
TPO_4	0.64	0.03	0.08	ND
TKN	4.4	3.0	2.1	1.9
NO_2+ NO_3	0.49	0.93	0.5	0.53
Ca	37	3	3	1.7
Na	2340	1000	139	1.51
Cl	1520	129	36	14
SO_4	32	9	ND	ND

Therefore any loadings derived from the monitoring sites reflect the area within the relative narrow width identified at the sites.

The total particulate matter (TMP) loadings were four times higher at the urban sites than at the rural sites. Also, the background deposition of metals are higher at urban sites, and show a significant contribution when compared to the wet deposition of metals.

Higher loadings observed in the fall at the Milwaukee site are well correlated with the higher wind data.

Monthly TPM loading rates observed over a 12 month period showed that the mean TPM at ground level was 1.14 kg/km/day, compared to 0.54 kg/km/day at an elevated level. This means that saltation represents approximately 50% of the TPM.

TABLE 3.5
COMPARISON OF TOTAL PARTICULATE MATTER AND ADT

Mean Total Particulate Matter - kg/km/day	Average Daily Traffic
29.5	117 000
28.7	87 000
8.5	14 000
1.1	26 000

Average monthly transport of total particulates from paved highway surface are shown in Table 3.6.

TABLE 3.6
AVERAGE MONTHLY TRANSPORT OF PARTICULATES
MILWAUKEE, ADT = 117,000, 8 LANES

Months	Total Particulate kg/km/day	Ave. Wind km/hr
April	22.5	17.5
May	27	18.1
June	20.4	18.0
July	21.7	13.0
August	21.1	15.2
September	20.1	15.6
October	36.3	19.3
November	30.7	19.6

A.3.2 Migration of Highway Contaminants (Kobriger, N.P. and Geinopolos, A., 1984)

Saltation refers to sand - sized particles which are injected into the atmosphere by vehicular turbulence.

Wind direction and speed affects the saltation rates. Usually highest total highway saltation rates occur in the spring, due to the dust and dirt build-up from the winter period.

The quantity of saltating particles reaching the right-of-way area particles is related to:

- Average daily traffic
- Wind speed and direction
- Available surface load
- Highway drainage design
- Proximity of travel lanes to right-of-way
- Landscape and its effects on wind

Four sites tested in the U.S. gave the following mean monthly saltation rates and average daily traffic in vehicles per day.

TABLE 3.7
SALTATION AND ADT

Total Particulates kg/km/day	ADT
9.3	115 000
11.0	90 000
1.2	32 000
0.7	27 000

A strong correlation exists between metals, such as Pb, Zn, Fe, Cr and Ni and saltating particulates as shown in the following Table.

TABLE 3.8
CONCENTRATION OF METALS ASSOCIATED WITH SALTATION
mg/kg

Lead	1 030 - 4 960
Zinc	191 - 1 880
Iron	20 900 - 44 700
Chromium	31 - 111
Nickel	ND - 207

According to the monitoring done in the U.K. (Colwill, et al.), the saltation caused by vehicle generated turbulence during dry periods is an important pathway for the partial removal of material from the pavement. The subsequent rate of deposition of pollutants on adjacent land falls off rapidly with distance.

A.4 THE QUALITY OF STORMWATER AS IT LEAVES AN OPERATING HIGHWAY-SUMMARY

The summary of Part A of the literature review is presented under a number of subheadings.

a) Effect of Land Use

It is difficult to separate the effect of land use on highway runoff quality. The strongest influence on water quality is the amount of traffic on the highway (ADT). Obviously, urban areas generate higher ADT levels. However, monitoring of wet and dry precipitation showed higher pollutant levels in urban areas than in rural ones. For example, the total particulates in the urban precipitation samples were on the average four times higher than the rural precipitation. This suggests that urban areas contribute, to some extent, to the pollutant levels in highway runoff through the higher pollutant concentration in the wet and dry precipitation.

b) Number of Lanes

Similarly to the remarks made under urban land uses, the number of lanes are reflected in the ADT, which showed the best correlation with pollutant loadings.

The two urban sites had eight lanes and as a result, carried 85,900 - 116,000 vehicles per day (ADT). The two rural sites had four lanes and carried 25,000 - 27,800 ADT. Therefore, the traffic per lane was almost twice as high at the urban area than at the rural monitoring sites.

The number of lanes are believed to be not a significant factor in the production of pollutants, except those extra particulates introduced by the application of de-icing agents on the extra lanes.

The presence of the GM type barriers identified a definite effect on the pollutant loads. These barriers stopped the movement of particulates to wind or vehicular traffic and thereby increased the pollutant loading in the runoff.

The number of vehicles travelled before a storm could not be correlated with pollutant loads according to the monitoring done at the Sacramento site by Envirex Inc., (Kerri, K.D. et al., 1985). Active freeway lanes do not retain significant amounts of pollutants. Particulates are blown off the travelled lanes to the shoulders and beyond.

During the antecedent dry period, the freeways are continuously swept by the traffic-generated turbulence.

It is believed that, during dry periods, there is an adherence of materials to the vehicles, whereas during a storm, there is more splashing and washing off these materials from the vehicles.

c) Climate

Rain, snow, wind and cold temperatures all can influence to some extent the quality of highway runoff.

Higher rainfall and snowmelt will produce higher pollutant loading. In addition, the cold climate regions where de-icing agents are used, will produce higher pollutant loading during the winter and early spring. For example, at

the U.K. monitoring site (Hedley and Lockley, 1975), the following was the monthly distribution of the total annual loading:

Month	%	Month	%
July	2	January	42
August	1	February	17
September	3	March	5
October	5	April	1
November	4	May	6
December	10	June	4
			100%

Where the prevailing wind blows part of the particulate matters away from the pavement, the runoff will contain lower concentration of particles.

d) Geographic Locations

Monitoring at the various geographic locations in the U.S. and Europe showed a wide range of pollutants. However, these variations were caused by the climate, number and type of vehicles, exhaust emissions, deicing practices, use of studded tires, velocity of traffic, absence of traffic jams, etc. There is no direct correlation between geographic location and pollutants in highway runoff.

e) Type of Drainage

Monitoring of highway runoff in grass and bare soil ditches showed lower concentration of pollutant than those measured at paved channels or in storm sewers. Bare soil ditches were found to be the most efficient in reducing pollutant concentration.

f) Pavement Type and Design Characteristics

Site characteristics will influence storm water quantity and quality. The U.S. Federal Highway Authority chose to classify sites into three types, each possessing different rainfall-runoff, runoff duration, pollutant accumulation, pollutant wash-off and constituent loading characteristics. These sites are described as follows (Kobriger, N.P. et al., 1981).

Type I Sites: Urban, elevated bridge deck, 100 percent paved, characteristic of urban freeway systems.

Type II Sites: Mountable curb, paved and non-paved areas, inlets spaced along the roadway surface.

Type III Sites: Rural, flush shoulders, paved (approximately 25 percent) and non-paved, runoff through grassy ditches with inlets spaced along ditch.

Thus, drainage design (typically associated with the urban or rural location of a site), will influence storm water runoff quantity and quality. Type I sites possess understandably high runoff coefficients, near unity and therefore, contribute to increased peak flows in streams, erosion and sediment transport into receiving waters. Other sites, Types II and III, contribute to the above problems to lesser extents since the unpaved areas attenuate runoff flows by action of infiltration. The degree of attenuation depends on many factors, e.g. soil type and topography which are all embodied in the rainfall-runoff relationships. Furthermore,

these latter sites provide some benefits in terms of runoff quality since the unpaved areas, typically vegetated, effectively reduce pollutant loadings.

Two of the U.S. monitoring sites, Sacramento and Harrisburg were at concrete highways, the other two at Milwaukee and Efland were asphalt pavements. Measurements showed no influence of the pavement type on runoff quality.

Generally, the median loading value for paved runoff events was at least an order-of-magnitude higher than for unpaved runoff.

g) Surrounding Land Use

The literature does not describe the effect of the surrounding land use on highway runoff quality. However, mention is made of the use of trees and shrubs in controlling the effect of wind and snow drifting.

h) Upstream Non-Highway Facilities Draining into Highway Drainage Facilities

No information available in the literature reviewed.

B. THE DEGREE TO WHICH THE QUALITY OF STORMWATER IMPROVES AS IT PASSES THROUGH A VARIETY OF PATHS

Highway runoff pollution control measures can be grouped in to the following three categories.

1) Source Management Measures

- Planning Measures
- Design and Operations
- Regulations

2) Post-Deposition Measures applied prior to runoff

- Street Cleaning
- Debris Removal, Spill Clean-Up

3) Post-Runoff Measures

- Infiltration System
- Vegetative Controls
- Wetlands
- Detention ponds
- Filtration Systems
- Flow alteration
- Catchbasins

The following pages summarize the literature review completed for the Federal Highway Administration in Management Practices for Mitigation of Highway Storm Water Runoff Pollution, Volume 2, Versar Inc., June 1985.

SUMMARY OF HIGHWAY RUNOFF WATER QUALITY MANAGEMENT MEASURES

Management Measure	POLLUTANT REMOVAL EFFECTIVENESS						
	Particulates	Heavy Metals	Pesticides PCBS	Organic Matter Hydrocarbons	Nutrients	Pathogenic Bacteria	Overall Rating
1. Source management Measures							
• Planning Measures	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Difficult to measure, probably moderate.
• Design and Operation	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Difficult to measure, probably moderate.
• Regulations: traffic, emission, inspection, litter, chemicals	High	High	High	High	High	High	Difficult to measure, probably high.
2. Post Deposition Measures							
• Street Cleaning and ditch maintenance	Low to Moderate	Low	Low	Low	Low	Low	Low
• Debris Removal, accident/spill Cleanup	Low to High	N/A	Low to High	Low to High	N/A	N/A	Moderate
3. Post Runoff Measures							
• Infiltration Systems	High	High	High	High	High	High	High
• Detention Basins - Wet	High	High	N/A	High	Moderate to High	Moderate to High	High

SUMMARY OF HIGHWAY RUNOFF WATER QUALITY MANAGEMENT MEASURES
(Continued)

Management Measure	POLLUTANT REMOVAL EFFECTIVENESS						Overall Rating
	Particulates	Heavy Metals	Pesticides PCBS	Organic Matter Hydrocarbons	Nutrients	Pathogenic Bacteria	
3. Post Runoff Measures (cont'd)							
• Detention Basins - Dry	Low to High	Low to High	N/A	Low	Low	Low	Low
• Vegetative Controls							
Grassed Channels	High	High	Moderate	High	High	High	High
Filter Strips	High	High	Moderate	High	High to Moderate	High to Moderate	High
Overland Flow	High	High	Moderate	High	High	High	High
• Wetlands	Low to High	High	N/A	Moderate to High	High	Moderate	High
• Catchbasins	Low	Low	Low	Moderate to Low	Low	Low	Low
• Filtration Systems	Moderate to Low	Low	Low	Moderate to Low	Low	Low	Low
• Flow Attenuation	Moderate	Low	Low	Low	Low	Low	Low

B.1 SOURCE MANAGEMENT MEASURES

B.1.1 Planning

Transportation planning can reduce the total vehicle kilometres travelled in an urban area and thus reduce pollution. Planning measures, such as mass transit, car pools, bicycles, have potential benefits, but the benefits are difficult to quantify.

Land use planning, such as density of development, traffic mix can reduce pollution. Increasing permeable areas, draining impermeable areas onto permeable areas, reducing development of highly permeable soils will further mitigate runoff pollution.

Erosion and sediment control planning for the construction phase will significantly reduce suspended sediment in runoff. The basic principles for erosion control are:

- Plan development to fit the site

  - minimize the disturbed area and duration of exposure;
  - apply erosion control practices, such as reducing runoff velocities, retain runoff and protect surrounding areas;
  - stabilize disturbed areas as soon as possible;
  - operation and maintenance of erosion control measures.

The following are the most frequently used erosion and sediment control practices.

- road stabilization
- sediment fences
- dikes
- diversions
- sediment banks
- waterway protection
- vegetation
- mulches
- temporary channel lining

B.1.2 Design and Operation

Design and operation of highways affect traffic volumes, density and duration which, in turn, affect the pollutant deposition.

The following is a brief description of design features which can affect runoff pollution loads:

Design Features

Barrier Elimination - Eliminating barriers from highways, to the extent practical, prevents many sediments and other particulates from being trapped on the highway. Without curbs, scour by wind and turbulence of passing vehicles will remove much of the fine materials from the road. The fine materials are associated with most of the pollutant load. Materials that are not trapped on the roadway are generally immobilized on the roadside. Barrier elimination as generally practised is a passive approach based on safety and cost considerations. Water quality is rarely the primary consideration.

Control of Traffic Flow - Reducing traffic density and minimizing stop-and-go traffic patterns on congested highways through signal synchronization, access ramp controls and other methods reduce pollutant generation and deposition. Idling vehicles in traffic result in incomplete fuel combustion, generating more pollutants.

Animal Control - Fencing of highway rights-of-way to minimize animal access to the highway improves safety conditions, reduces accidents, and thereby lessens pollutants from spills, debris, and litter.

Operational Features

Fertilizer Application - The use of fertilizers, particularly in areas with direct runoff to natural receiving waters, should be controlled to prevent unnecessary releases of nutrients. Management controls on fertilizer application (type, rate, frequency, time, site, etc.) can reduce the chemical residues available to be transported by stormwater runoff. Highway agencies typically limit fertilizer application to areas of new establishment or problem areas with poor vegetative cover. Applicators are usually trained and licensed under a regulatory program. The following concerns are significant in the prevention of fertilizer runoff:

- Using erosion control (e.g. mulch) practices for newly vegetated sites.
- Applying only the necessary fertilizers.
- Applying fertilizer only when there is adequate soil moisture and little likelihood of heavy rain.

- Timing fertilizer application to the needs of the vegetation.

Pesticide/Herbicide - Pesticides and herbicides are poisons that vary widely in their toxicity and persistence. They can cause significant acute and chronic toxic responses in terrestrial and aquatic ecosystems. Pesticides/herbicides were not found to be significant pollutants in highway runoff (Kobriger, Gupta, Geinopolos, 1982). Pesticides are infrequently used by highway agencies and personnel involved are trained and licensed. Herbicides are occasionally used in lieu of mowing, and for noxious weed control. The following are general guides for minimizing the pesticide/herbicide load in runoff:

- Other factors being equal, the least toxic chemical that will accomplish the purpose should be used.

- Pesticides/herbicides that degrade rapidly should be used because they are less apt than others to become water pollutants.

- Pesticides/herbicides with low solubility in water should be used because they are less apt than others to cause water pollution through drainage and runoff. Loss of such chemicals can be greatly reduced by preventing erosion.

- Some pesticide/herbicide formulations have a broad spectrum of activity. These should be used whenever possible instead of serial applications of highly specific materials.

The type of substance used affects the water pollution potential, as do timing and weather conditions. Other factors include topography; proximity to people, natural water bodies, sensitive ecosystems, etc; dosage and disposal of surplus pesticides and contaminated equipment.

Types of substances and some broad guidelines are:

- Dusts - Are highly susceptible to wind drift, not only when being applied but also after they reach their target. If dusting offers the only acceptable control practice, the operation should be carried out during the early morning or late evening hours when there is low air movement. The distance between the application equipment and the target is also a factor to consider.

- Sprays - May be in the form of solutions, emulsions, or suspensions. Droplet size is an important factor in determining susceptibility to wind drift. Large droplets fall faster and are less likely to contaminate non-target areas. Apply during periods of low air movement. Ground sprays followed by soil incorporation are not likely to be a source of water pollution unless excessive erosion occurs.

- Granular Formulations - Are applied to either the surface of the ground or below the soil surface. Surface applications may or may not be followed by soil incorporation. Pollution from granular formulations is unlikely unless heavy runoff or erosion occurs soon after treatment. Loss of granular formulations can be controlled for the most part with adequate soil conserving practices.

- Fumigants - Must be kept in place for specific lengths of time in order to be effective. Containment methods include soil compaction, water seal and sealing of the area with a plastic cover. Grain bins, etc., are usually sealed with masking tape. Most fumigants act rapidly and degrade quickly. Water pollution is usually not a problem associated with fumigants.

- Antimicrobial Paints and other Surface Coatings - Are designed to resist weathering and are therefore not considered as likely sources of pollution. Empty containers, however, should be disposed of in accordance with the rules for all pesticide containers.

- Preplant Treatments - Seed, roots, tubers, corms, etc. are frequently treated with pesticides prior to planting. Treatment is usually by dust, slurry or liquids. Little pollution hazard exists from use of treated plant parts. Care must be taken, however, in disposing of unused treated plant parts and residual treatment materials. The same standards applicable to disposal of other pesticides should be observed.

- Mowing Debris Control - Grass mowing, shrub and tree trimming and other vegetative maintenance operations can leave cuttings and other debris along highway shoulders and rights-of-way. This debris can form a thatch layer, reducing infiltration and preventing other vegetative growth. If transported by stormwater runoff, the debris can become part of the pollution problem. However, mowing debris does not contribute significant amounts of pollutants to the runoff. Collection of cuttings and other debris during vegetation maintenance activities, if practical, can reduce this minor pollutant source.

Areas with sparse vegetative cover and areas prone to erosion can benefit from leaving cuttings on the ground. The cuttings can act as a mulch, reducing erosion, preserving soil moisture, and adding organic matter to the soil.

B.1.3 Regulations

Laws and regulations affecting traffic, vehicle emission, vehicle inspection, litter controls, are also influencing the pollutants deposited on highways.

- Traffic Regulations - Involve speed limits, volume control and vehicle mix.

- Vehicle Emission Controls - Control of vehicle emissions through air pollution control devices and restrictions on lead in fuels has caused significant reductions in air pollutants, with resultant reductions in pollutant deposition on highways.

Possible measures to ensure compliance (many are transportation control measures):

1. Motor vehicle emission inspection and maintenance programs.

2. Programs to control vapour emissions from fuel transfer and storage operations and operations using solvents.

3. Programs for improved public transit.

4. Programs to establish exclusive bus and carpool lanes and area-wide carpool programs.

5. Programs to limit portions of road surfaces or certain sections of the metropolitan areas to the use of common carriers, both as to time and place.

6. Programs for long-range transit improvements involving new transportation policies and transportation facilities or major changes in existing facilities.

7. Programs to control on-street parking.

8. Programs to construct new parking facilities and operate existing parking facilities for the purpose of park-and-ride lots and fringe parking.

9. Programs to limit portions of road surfaces or certain sections of the metropolitan area to the use of non-motorized vehicles or pedestrian use, both as to time and place.

10. Provisions for employer participation in programs to encourage carpooling, vanpooling, mass transit, bicycling and walking.

11. Programs for secure bicycle storage facilities and other facilities, including bicycle lanes, for the convenience and protection of bicyclists, in both public and private areas.

12. Programs of staggered hours of work.

13. Programs to institute road user charges, tolls, or differential rates to discourage single occupancy automobile trips.

14. Programs to control extended idling of vehicles.

15. Programs to reduce emissions by improvements in traffic flow.

16. Programs for the conversion of fleet vehicles to cleaner engines or fuels, or to otherwise control fleet vehicle operations.

17. Programs for retrofit of emission devices or controls on vehicles and engines.

18. Programs to reduce motor vehicle emissions which are caused by extreme cold start conditions.

- Vehicle Maintenance Inspections - Vehicle maintenance can also reduce pollutant levels. Pollutant reductions are achieved by application of the same basic preventive steps often described for air pollution control, fuel conservation and other maintenance programs. Several specific maintenance measures to reduce potential release of pollutants are:

  - Keep brakes and tires in good condition. Proper wheel alignment and tire balance reduce tire abrasion and particle deposition on pavements.

  - Avoid "topping off" gas tanks to reduce the amount of gasoline spilled on streets and to reduce surface deterioration.

  - Stop leaks in radiators, oil pans, and transmission to prevent the escape of fluids that directly pollute.

- Obtain regular tuneups. Tuneups reduce the amount of incompletely burned fuel emitted from tailpipes, thus reducing the amount reaching runoff.

These maintenance measures may be applied voluntarily; however, they are not universally observed. Public education and/or mandatory inspections on a regular basis can expand the source management potential.

- Litter Control - Litter, defined as "uncontainerized solid waste", is the trash found along roadsides, vacant lots and sidewalks. Litter is biodegradable (although plastic litter may have an extremely long life) and creates an oxygen demand in water during decomposition. Litter acts as a transporting mechanism for other pollutants, and in sufficient quantities can clog drains, waterways, etc.

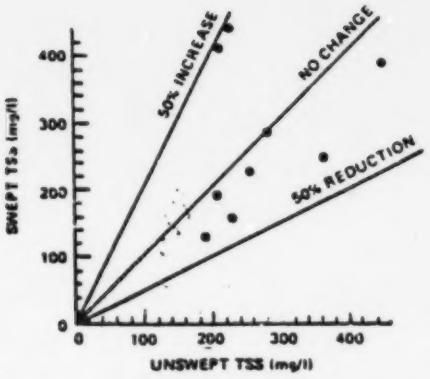
B.2 POST-DEPOSITION MEASURES

B.2.1 Street Cleaning

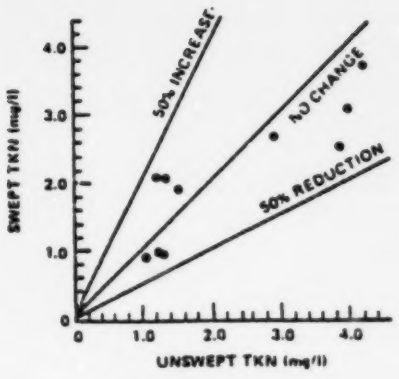
The primary purpose of street cleaning practices has been to improve the aesthetic appearance of streets through periodically removing litter, dirt and other debris. Street cleaning practices are applicable for all paved vehicular traffic areas, particularly those areas having curbs and gutters. Consequently, street cleaning was commonly considered an important management practice for reducing stormwater runoff pollutant loadings in urban areas.

Research has clearly established that the majority of nutrients, pesticides, heavy metals and oxygen-demanding pollutants in highway stormwater runoff are attached to fine particles. Street cleaning reduces pollutant loadings by removing most of the large solids and particles, but is ineffective in removing the fine particles containing most of the pollutant load. Based on recent studies by US EPA (1983), street cleaning has been shown to have virtually no effect on pollutant loadings in runoff. (See enclosed Figure 1 from the studies.).

Present methods of street cleaning fall into two categories: street sweeping and street flushing. Street sweeping is performed by hand or by using mechanical broom sweepers. The basic procedure when operating a street sweeper is for the sweeper to clean a swath, the length of the street adjacent to the curb. The majority of particulates on the streets accumulate along the sides due to wind turbulence from traffic. Kobriger et al. (1982) found that pollutants associated with solids tend to accumulate near curb lines.



TSS CONCENTRATIONS



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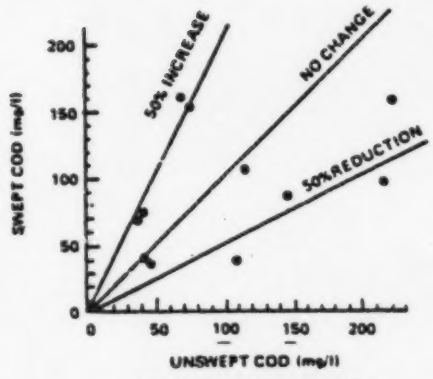

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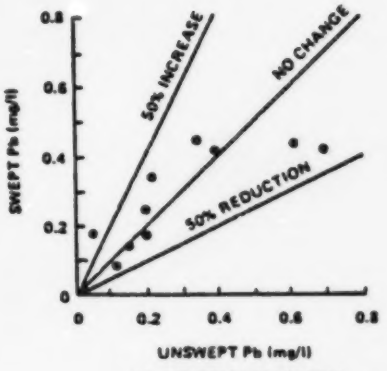
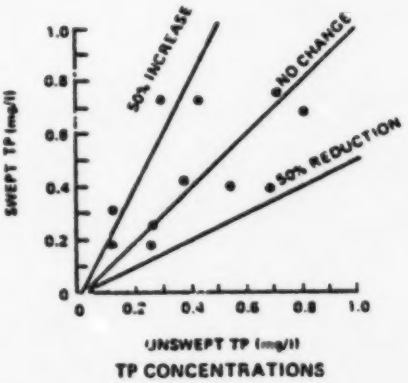


Pb CONCENTRATIONS



TP CONCENTRATIONS

KEY:

TSS = TOTAL SUSPENDED SOLIDS
TKN = TOTAL KJELDAHL NITROGEN
COD = CHEMICAL OXYGEN DEMAND
Pb = LEAD
TP = TOTAL PHOSPHOROUS

TO CHANGE mg/l TO gr/gal., MULTIPLY BY 0.058

Figure 1. Street sweeping effectiveness.
Source: USEPA 1983.

Street sweeping can remove most of the large litter and debris from the street surface; however, fine solids containing most of the pollutant load are virtually unaffected. Street flushing merely moves debris from traffic lanes into the gutter, and has no pollutant removal capability.

.B.2.2 Accident/Spill Clean-Up

Debris removal and accident/spill clean-up activities are performed primarily for aesthetic and safety reasons. Although some pollutant reduction benefits may be claimed, the failure of most clean-ups to remove fine particles reiterates the problems associated with street sweeping. The exception occurs when a particularly toxic or otherwise obnoxious contaminant is spilled or accidentally leaked in a form which could be transported by stormwater runoff. Since these are isolated events, they do not contribute to the overall long-term nonpoint source pollutant loading of an area. However, the potential impacts of toxic spills on the local receiving waters can be significant. Most highway agencies in the U.S. have established programs to handle emergency clean-ups and periodic debris removal. These programs are often part of the standard litter control maintenance activities.

Typical accident or spill clean-ups are by hand. Where a rapid clean-up is required, the highway may be flushed with water. Flushing is also used in combination with chemical applications on some hazardous materials. No data were found concerning the pollutant removal effectiveness of these practices.

B.2.3 Ditch Maintenance

Ditch maintenance involves cleaning and shaping roadside ditches to restore proper grade and side slope configuration to assure proper drainage. Foreign material (debris or sediment) and vegetation accumulate in ditches and impede the flow of highway runoff. The purpose of ditch maintenance is to ensure the capability of the ditch to convey stormwater runoff in an efficient manner. Ditch maintenance is therefore a highway runoff disposal method, and is not intended to perform or encourage pollutant removal functions.

The removal of sediment deposits and vegetation from ditches has both potential advantages and disadvantages for mitigating highway runoff pollution. The sediment and vegetation removed will contain pollutants filtered and adsorbed from the highway runoff, the removal prevents these pollutants from being resuspended or transported by later storm events (assuming proper disposal of the excavated material). The disadvantage lies in the ditch being stripped of its protective vegetative cover, thereby increasing flow velocities and potential for erosion, and decreasing the removal of pollutants.

Vegetated ditches are an effective mitigation measure for removing pollutants from highway runoff, and are a recommended management practice. Therefore, ditch maintenance which removes debris and sediment deposits while retaining or encouraging vegetation (especially grass) is preferred. Vegetated ditches will require gentler side slopes and grades and thus more land within the right-of-way, a potential limitation.

B.3 POST-RUNOFF MEASURES

These measures remove pollutants from runoff after it left the highway system.

B.3.1 Infiltration Systems

An infiltration system is a method whereby surface runoff is temporarily stored, allowing it to infiltrate into the ground rather than to follow a surface course in natural drainage channels. Infiltration techniques can be used to achieve several purposes, including:

- To control or reduce the amount of stormwater runoff.
- To maintain recharge of major aquifers and other ground water resources.
- To remove pollutants from stormwater runoff.

Infiltration is the movement of water from the soil/air interface into the soil. Percolation is the movement of water within the soil. Infiltration and percolation are closely related, with the lesser of the two controlling the rate of function for an infiltration system. Field infiltration capacity curves approach a steady minimum rate after less than one hour (U.S. DOT 1979). The Unified Soil Classification System describes minimum infiltration rates for the more commonly encountered soil groups:

Description	Unified Soil Group Symbol	in/hr	mm/hr
Sand and gravel mixture	GW,GP SW,SP	0.8 - 1.0	20.3 - 25.4
Silty gravels and silty sands to organic silt and well developed loams	GM,SM ML, MH OL	0.3 - 0.6	7.6 - 15.2
Silty clay sand to sandy clay	SC,CL	0.2 - 0.3	5.1 - 7.6
Clays, inorganic and organic	CH,OH	0.1 - 0.2	2.5 - 5.1
Bare rock, not highly fractured	---	0.0 - 0.1	0 - 2.5

These infiltration values are for uncompacted soils. Soil compaction decreases infiltration rates by 25 to 75%, depending on soil characteristics and degree of compaction. Vegetative cover increases infiltration capacity over bare soils, particularly for forest and grass cover. Other factors affecting infiltration include soil type, organic matter, moisture content, season and rate of precipitation.

Infiltration systems fall into two general categories.

1. Systems that infiltrate runoff after it has been collected, including:

   - Infiltration basins - An infiltration basin is an excavation or basin in or down to relatively permeable soils.

     Infiltration basins consist of excavations in relatively permeable soil. A basin temporarily stores surface runoff to facilitate infiltration through the bed and sides of the basin. Infiltration basins are applicable where there are relatively permeable soils and a minimum of 3 m distance exists

between the basin bed and the ground water table (Becker et al., 1973). As most percolation occurs at the bed of the basin, and at an increased rate when under a large head of water, infiltration basins are often designed with deep, steep sides.

It is rarely feasible to construct a basin large enough to infiltrate all runoff from the storm of record due to costs and other restrictions. Tourbier and Westmacott (1980) recommend that a basin be designed to store and recharge most of the annual precipitation. Provisions must be made for storms exceeding the design storm. Infiltration basins on Long Island, New York, are designed primarily for highway runoff. These basins are devised to store runoff from an "instantaneous rainfall" of 12.5 cm over the entire watershed. Basins used by the California Division of Highways in the Fresno area vary in size from 0.4 to 2.4 ha, and are designed to store two consecutive 24-hour storms with a 10-year frequency. Tourbier and Westmacott (1980) note that infiltration rates during the runoff concentration period are not considered during design. An additional factor in design is the availability of land. Where suitable land is limited, basins may need to be deeper to achieve adequate storage capacity.

- Drainage wells - A drainage well, also called a diffusion well, is a vertical shaft extending to previous strata. The shaft may be lined with concrete (precast), or metal pipe, or simply filled with sand, gravel, or other filter material.

- Deep infiltration wells - A deep infiltration well (often known as an injection well) is a deep, small-diameter well. These deep wells are most often used with a detention basin.

- Shallow infiltration pits and trenches - A shallow infiltration well or trench is simply an excavation backfilled with sand or gravel. The excavation may vary in size and shape, but is relatively shallow and resembles a trench or pit.

Drainage wells are advantageous where poorly drained soils overly relatively permeable subsoils. However, they are unsuitable in areas with a high water table or an impermeable subsoil.

Tourbier and Westmacott (1980) state that small diameter shallow holes have shown great promise as recharge devices for stormwater runoff. However, Weaver (1971) indicates that drainage wells are the least desirable infiltration method for disposing of highway runoff due to high cost and low efficiency. As storage space in most wells is limited, a basin may be necessary to hold the inflow prior to infiltration through the well. Use of a filter material as a backfill in the well reduces the storage space. Thus, in some cases, wells are not suitable alternatives to basins but are an extra cost, added to correct inadequate design or maintenance of infiltration basins (Weaver, 1971). Jackura (1980) concludes that wells are limited in their capacity to drain surface water.

Wells are susceptible to clogging from silt and sediment in the inflow. Jackura states that filtration must be effected prior to entry of inflow into the well by mounting a filter material outside the well entrance. A mushroom-shaped

filter, projecting about 1.2 m above the basin bed, located on top of the well, is sometimes used to prevent inflow of sediments (Weaver 1971).

Monitoring reported by Harwood (1986) describes a 450 mm wide infiltration trench (french drain) with a 150 mm diameter perforated PVC pipe, which was used to treat motorway runoff in the U.K.

Results of the experiments were as follows:

	Removal Efficiency (%)	Loading (kg/km/year)
TSS	85	225
Pb	83	0.68
TZn	81	1.52
Zn (SA)	84	-
Zn (D)	56	-
COD	59	-
Oil	70	37.8
PAH	70	5.4×10^{-3}

2. Systems which infiltrate stormwater on-site, reducing runoff.

   - Porous pavement - Porous pavement allows water to percolate through it into the soil or substrata below.

     Porous pavements have limited potential for abating pollution from highway stormwater runoff. Application is confined to low traffic volume highways, and pollutant loads in runoff from such highways is not significant. Use of porous pavement is further

limited by the lack of long-term structural data and data on its capabilities to remove pollutants, as well as the need for subsoils with sufficient permeability to infiltrate the runoff stored in the pavement reservoir. Design and engineering of porous pavements require careful consideration of these limitations. Other disadvantages are the potential for clogging by sediments or ice, the difficulty of construction and oxidation of the asphalt (greater surface area exposed). However, with normal maintenance precautions, clogging is seldom a problem, and if the pavement becomes sediment-clogged, it may be cleaned by street sweeping or flushing. Ice is considered to have low potential for clogging the pavement.

On the other hand, porous pavements can have several advantages:

- Attenuation of runoff.
- Improved erosion control.
- Minimized water quality degradation.
- Less need for curbs and storm sewers.
- Retention of natural drainage patterns and vegetation.
- Improved road safety.
- Ground water recharge.

In summary, infiltration systems are applicable where the soil is relatively permeable and the ground water table is not too close to the point of discharge. In some cases, inflow may be discharged directly into the ground water, although this is not generally recommended. Basins are the most economical and efficient means for removing pollutants from highway runoff drainage. Trenches and pits are suitable

for some situations, including many parking lots. Wells are not generally recommended because of their high relative cost per volume of water infiltrated. However, wells work satisfactorily in conjunction with infiltration basins, increasing access to permeable substrata.

Porous pavements are not suitable for high-volume highways or heavy vehicular traffic because of potential structural problems resulting from saturation of subgrades.

Little data are available concerning the pollutant removal effectiveness of the various infiltration methods that are designed to store and infiltrate collected runoff. Infiltration methods function by temporarily retaining all or a portion of the inflow until it infiltrates, percolates, or evaporates away. There is no outflow until the storage capacity is exceeded. Pollutant removal efficiencies (in terms of surface runoff) are therefore 100% up to the point where the storage capacity is exceeded.

As pollutant removal occurs in the soil, pollutant removal effectiveness is highly site dependent. Soil characteristics play a major role, particularly cation exchange capacity, clay mineral content, organic matter, pH, soil structure and depth to water table. To avoid clogging of the soil, sediment and other suspended material should be removed from the inflow prior to infiltration. Best results in terms of pollutant removal and runoff disposal come from sediment basins in conjunction with infiltration basins. The sediment basins intercept the runoff prior to infiltration.

Pollutant removal processes are physical, chemical and biological, involving adsorption, filtration, precipitation, decomposition, chemical adsorption and biological transformation and degradation.

The natural filtration of runoff water by the soil removes most contaminants. Most pathogenic bacteria and many chemicals are filtered out within 0.9 to 3 m of vertical percolation and 15 to 60 m of lateral water movement (Jackura, 1980). However, soil and underlying strata characteristics are highly site specific, making accurate predictions of pollutant filtration difficult. Soil properties generally considered important for filtration and retention of pollutants are pH, cation exchange capacity, clay mineral content, organic matter content, pore space and structure. The height of the water table, including seasonal fluctuations, is also an important parameter.

In most infiltration methods, the topsoil has been removed or by-passed. The porous subsoil materials are typically low in organic matter content, low in microbial activity and may vary widely in permeability.

Vegetative controls involve the use of vegetated surfaces to manage stormwater runoff from highways. The natural capability of vegetated surfaces can be utilized to reduce velocity of runoff and enhance sedimentation, filter suspended solids, increase infiltration and remove runoff contaminants. The successful applications of these controls are dependent upon flow velocities and depth, slope, soil characteristics (i.e. porosity, erodibility, etc.), water table depth, type and density of vegetation and maintenance. Although a reduction in runoff velocity which causes an increase in sedimentation is generally regarded as a beneficial aspect of vegetative controls, sufficient velocity must be maintained to adequately provide conveyance for drainage.

Vegetative controls include:

- Vegetated waterways - A vegetated waterway is a ditch, channel or swale with a cover of vegetation designed to reduce runoff velocity and enhance settling of suspended solids.

- Filter strips - Filter strips are strips of vegetation designed to accept overland sheet flow with the purposes of retarding the runoff velocity and increasing infiltration.

- Overland flow - Overland flow is a larger-scale application of the filter strip concept, where runoff (as sheet flow) flows over vegetated land to remove pollutants.

Most U.S. highway agency drainage manuals, the FHWA Hydraulic Engineering Circular No. 15, "Design of Stable Channels with Flexible Linings," and Volume VI, AASHTO Highway Drainage Guidelines, "Hydraulic Analysis and Design of Open Channels," provide excellent guidance for the design of stable grassed channels. The literature is replete with "rules-of-thumb" for designing vegetative waterways, but this approach should be relied upon only where engineering expertise is unavailable and the consequences of failure will be insignificant.

Vegetated waterways may be built in three shapes or cross-sections: parabolic, trapezoid, or "V" shaped. Poland (1975) notes that the parabolic design is the most satisfactory, and is ordinarily the shape found in nature. The waterway should be designed to allow equipment crossing when necessary. Where mowing or other maintenance is planned, side slopes should not exceed 4:1 (Amimoto 1978; Tourbier and Westmacott 1980b). Sharp turns should be

avoided as they are potential problem areas for erosion or debris jams. Vegetative cover will vary in its ability to withstand erosion according to type, density and soil. Therefore, safe velocities and designs are site-specific decisions.

Filter strip width is the key dimension for overland flow treatment of highway runoff. The width necessary to achieve the desired level of pollutant reduction will vary from a few feet in relatively well-drained flat areas to several hundred feet in steeper, more impermeable areas (VSWCC 1979). Although pollutant removal effectiveness is directly related to filter strip width, pollutant removal per unit width of filter strip is greater for narrower filter strips (Westerman, Overcash and Bingham 1983). Thus, as the filter strip width increases, there is less improvement in water quality per unit width.

The pollutant removal effectiveness of vegetation is dependent upon the species characteristics (size, shape, density) and the density of the plant stand. Generally, more dense vegetation and plant stands cause increased sedimentation, filtration, infiltration and adsorption of colloidal-sized particles. Grass is the most commonly used vegetation.

The following water quality improvements are characteristics to vegetated waterways:

- Reduction of nutrient concentrations by soil and vegetative processes.

- Breakdown of hydrocarbons by bacterial degradation.

- Settling of solids because of the vegetative filtration system.

- Complexing of the metals by soil adsorption and biological assimilation.

Advantages of grass waterways, which are generally applicable to all vegetative control systems, are as follows:

- Unobstrusive and fit well into the terrain.

- Grass reduces velocity and energy of runoff.

- Are relatively inexpensive to construct and maintain.

- Increase infiltration of runoff and the availability of soil moisture to vegetation on site.

Design considerations of grass waterways are:

- Careful sizing and design are essential if grass waterways are to function effectively without erosion damage.

- Grass waterways are rarely designed for maximum flows. Erosion damage must be repaired and grass re-established after large flows in order for the waterway to function effectively for pollutant removal.

- Side slopes should be relatively flat for safe mechanized mowing and for roadside safety.

Stormwater runoff from highways can be effectively treated through vegetated controls (Mar et al., 1982). Channelling highway runoff in Washington State through 30 m of grass

Table 5. Grass channel metal removal efficiencies, Washington State.

Site	Distance[1] (m)	No. samples	Removal efficiency (%)[2] Cd[3]	Cu	Fe	Mn	Pb	Zn
I-5 @ N.E. 158th	15-21	6	51.4 (46.0)	24.6 (46.0)	53.8 (31.2)	40.5 (25.2)	59.3 (18.8)	35.5 (16.1)
	31	1	60.0	53.5	53.1	50.6	70.4	31.4
	40-50	6	80.0 (44.7)	39.2 (22.6)	73.4 (12.6)	61.2 (32.3)	72.0 (15.0)	69.7 (10.4)
	67	6	100 (0)	63.1 (24.0)	76.7 (9.2)	54.3 (43.2)	83.8 (11.7)	69.7 (10.4)
I-5 @ N.E. 159th	15-20	2	100	40.1 (37.8)	39.7 (11.4)	59.4 (1.4)	37.5 (0.1)	23.6 (14.6)
	30-40	2	100	51.1 (19.2)	35.1 (17.6)	62.0 (0.6)	54.1 (5.0)	50.8 (9.8)
	50-60	2	34.8	20.3 (19.7)	54.0 (2.1)	75.0 (7.8)	66.9 (20)	64.2 (1.3)
	67	1		43.4	62.0	93.3	90.2	65.4
	77	2		57.5 (7.4)	70.5 (33.9)	91.8 (6.5)	80.6 (15.3)	72.1 (14.6)
I 405 @ Kirkland	2.5	1		< 0	3.6	1.2	2.9	2.1
	10.0	1		29.3	39.8	49.2	58.6	16.6
	15.0	1		51.9	54.9	83.6	68.1	19.4
	20.0	1		63.7	49.9	81.9	77.3	45.9
	25.0	1		70.7	63.3	83.4	86.7	57.1
I-5	2.5	1	< 0	< 0	8.1	19.3	2.1	12.9
	5.0	1	45.8	34.4	68.0	72.9	72.4	60.2
	15.0	1	100	68.1	80.4	84.7	78.5	93.2
	25.0	1	100	53.3	76.0	78.1	82.4	94.0

[1]Distance runoff flowed in channel from beginning of vegetated area.
[2]Mean (standard deviation) given for multiple samples.
[3]One or more values were below detectable limit.

To change m to ft, multiply by 3.3.

Source: Wang et al. 1981.

channel removed 60 to 80% of the lead, zinc, and copper contaminants. Wang et al. (1981) sampled grass channels at four Washington highway sites and concluded that 60 to 80 m of grassed waterway removed the majority of the metals from the runoff. Lead was removed more effectively than other metals, presumably because of its low solubility and strong association with particulates. Results of the study by Wang et al. are shown in Table 5.

The most detailed information on the performance of vegetative waterways is given in "Removal of Highway Contaminants by Roadside Swales" (Yousef et al., 1985).

Two locations in Central Florida were monitored for removal of heavy metals. One was an older established swale at Maitland (north of Orlando), the other sandy, newly constructed swale at EPCOT.

At both sites, individual events were sampled, followed by another set of tests with continuous flows. With the continuous pumping from a pond, concentrated solution of heavy metals were added to the flow. Water samples at various distances were collected every 30 minutes, ranging from 3 to 5.5 hours. Averages measured over the entire test period were used to estimate the removal during the continuous experiments.

The first site at Orlando had thick crop of grasses, predominantly Bahia. The EPCOT site had tests shortly after construction with earthen bottom and sides, with 20% grass cover. This subsequent test later had 80% grass cover.

The summary of samples at Orlando, Maitland site showed that the heavy metal content at the swale was lower than in the highway runoff.

Comparison of average concentrations in water samples showed that both total and dissolved forms of every metal analyzed were lower in swale flow than highway flow. On the contrary, water samples from swale flow contained higher average concentrations of the nutrients, P and N than highway runoff.

Zn concentrations were decreased to the greatest degree through swale areas with average reductions of 82 and 90% in dissolved and total species, respectively. Concentrations of Pb decreased 91 and 50% for total and dissolved species, respectively. Cu, Cd and Cr concentrations decreased the least degree through swale areas, with an average reduction of 29 to 44% in total metal, and 13 to 19% for the dissolved metal. It is assumed that the particulate metal fractions are removed through the swales at a higher percentage than the dissolved fraction as a result of filtration of particulate matter during transport through grassy covers.

Similar results were obtained during the simulated continuous flow swale experiments performed at the Maitland and EPCOT sites. The Maitland site showed the greatest reduction in dissolved Zn and Fe with averages of 86 and 69% removal, respectively. Removals of dissolved Pb, Cu and Cr were not significant. Under controlled conditions, however, reductions in nutrient (N and P) concentration were indicated that averaged 24, 25, 31, 13 and 6% for OP-P, TP-P, NH_4-N, (NO_2 + NO_3)-N and TN, respectively. Organic nitrogen increased in concentration by 13% after flowing 53 m along the swale area.

Removal rates of 62, 57, 43 and 51% for Zn, Pb, Cd and Ni, respectively, were observed at the EPCOT site. All other measured parameters decreased slightly or increased after flowing 170 m. This site was a newly constructed swale with

very little vegetation, a high water table elevation, and was nearly saturated with water during the swale experiments.

The conclusions drawn by the study were:

- Swales built on high ground with good drainage and high infiltration rates showed better removal efficiencies for highway contaminants. Results from EPCOT suggest that removal of heavy metals decreases significantly in swale areas that are low and constantly wet.

- Swales appear to be more effective in reducing concentrations of metals that N and P in a flow-through situation. These efficiencies are governed by the predominant ionic species and complexes. Charged species are retained by sorption processes. Swales filter out particulate heavy metal and incorporate them into the soil. Heavy metals in highway runoff with large particulate fractions show higher removal efficiencies.

- Removal of heavy metals may be caused by precipitation and sorption processes; therefore, charged ions and complexes may be removed more efficiently than stable complexes and non-charged particles.

The efficiency of swale for removal of pollutants can be increased by increasing contact time and infiltration rates; therefore, the following recommendations are made:

1. Reduce longitudinal slopes of future roadside swales as much as possible.

2. Increase contact surface within the swale area by increasing the wetted perimeter-to-cross section area ratio by using relatively flat side slopes whenever possible.

3. Whenever possible, avoid building swales in areas where portions remain wet most of the time as a result of low ground and high ground water tables.

4. Construct earthen cross barriers (swale blocks) at selected length intervals along the swale to retain additional water, so that the maximization of on-site retention by storage of runoff water in swales built on upland areas may be achieved.

5. Plant a cover crop for erosion control and follow effective maintenance procedures; removal of grass clippings, loose debris, and litter is desirable if practical; also, consider slow growing grass species with low maintenance requirements.

Grass filters and overland flow have also been proven effective in pollutant removal from highway runoff, urban runoff and municipal wastewater. Removal efficiencies of grass and grass-soil filter strips for some common runoff pollutants are shown below (VSWCC, 1989). These percent reduction efficiencies are not directly applicable to grassed waterways due to the differences in runoff velocity.

Pollutant	Percent Reduction[1]	
	Grass	Grass-Soil
COD	19	88
Suspended solids	34	99.6
Volatile suspended solids	26	97
Turbidity	97	98
Total coliforms	84	98
Fecal coliforms	50	98

1. "Grass" refers to the effect of grass alone; "grass-soil" refers to the effect of both the grass and underlying soil.

The effectiveness of vegetative control of runoff comes from continuous vegetation, as it is the vegetation that reduces runoff velocity, thereby enhancing sedimentation, filtration, infiltration and adsorption of pollutants. Grass is the most effective vegetation for pollutant removal and erosion control (ABAG, 1981). Trees and shrubs are not as effective, as not enough of the surface area is protected. Flowers are more effective than trees and shrubs but less effective than grass. Tall dense stands of turf-forming grasses are the most effective.

Selection of suitable vegetation is dependent upon several parameters, the importance of which will vary according to the site and locality of the vegetative control measure.

The following criteria is suggested in selecting vegetative cover.

- Erosion-control effectiveness.
- Commercial availability of materials.
- Cost to apply and maintain.
- Drought and frost tolerance.
- Fire hazard.
- Adaptability to site conditions and climate.
- Compatibility with the surrounding landscape.
- Level of maintenance required.
- Life span.
- Hardiness and durability.
- Suitability for providing specific control of runoff and pollution.
- Slope and permissible design velocity.

Satisfactory performance of the vegetation depends on proper shape and preparation of the site to provide favourable vegetative growth. Site preparation involves some combination of seed bed preparation (i.e., roughing or breaking up the ground so it can hold seed); topsoiling; and application of fertilizer, lime or other soil conditioners.

Mulch and irrigation are also important to vegetative establishment; however, irrigation requirements and feasibility are variable by locality. Application of mulch increases vegetation survival rates and protects both site and seed from wind and water erosion. Commonly used mulches include straw, wood fibre, wood bark or chips, fabric mats, soil and occasionally gravel. Selection of mulch is dependent upon site characteristics, product availability, cost and effectiveness. Straw mulch generally offers the best results for erosion protection and vegetative establishment.

The critical period for vegetation establishment is the first year; however, as much as three years growth may be necessary to establish stable turf growth via seeding. Where immediate cover is required, grass sod should be used.

Maintenance is an important factor in preserving an adequate vegetative cover on many sites, particularly those difficult areas not well-suited to grass establishment. Maintenance practices for vegetative control include fertilization and mowing needs. Irrigation of newly seeded areas may also be required. Vegetated waterways should be inspected periodically for erosion, debris jams and health and condition of the vegetative cover. A key concern for filter strips and overland flow areas is the maintenance of soil porosity. This may require periodic removal of the thatch or mechanical aeration. Accumulated sediment may also require removal. Repairs (seeding or sodding) should be made as needed to maintain a suitable vegetative cover. Unfortunately, there are no precise performance standards. A filter strip or waterway with 75% vegetative cover may be adequate for pollutant removal at one site and ineffective at another site.

Where vegetative controls are used alongside highways and in place of curb-and-gutter systems, care should be exercised to prevent adverse impacts on either the vegetative control or the traffic.

- Vegetated waterways are generally less expensive to install than curb-and-gutter systems.

- Roadside waterways keep flow away from the street surface during rain storms, reducing the potential for hydroplaning of auto tires and for wet brake linings.

- Vegetated waterways may require more maintenance than curb-and-gutter systems (mowing, seeding, debris removal, erosion and sediment control).

- Roadside ditches are subject to damage due to snow plowing and offstreet parking.

- Streets with vegetated waterways may require some rights-of-way and may be less compatible with sidewalk systems.

- Roadside vegetated waterways become less feasible as the number of driveway entrances requiring culverts increases.

- Roadside vegetated waterways can be used in conjunction with infiltration trenches and pits to further attenuate runoff and improve its quality.

- Where driveways and intersections are infrequent, roadside safety is enhanced by the use of roadside ditches for drainage in lieu of curb-and-gutter sections.

Several environmental factors should be considered in the design and operation of vegetative control measures for highway runoff. One of the primary environmental considerations is the effect of climate, including site-specific microclimate on the vegetative control. The amount, type and timing of precipitation will restrict the type and species of vegetative control. The size of storm events, particularly the design storm, will influence the size and configuration of the ditch or waterway. Winter, with its periods of freezing temperatures which inhibit runoff and cause death in some vegetation, is also a limiting factor. Microclimate of

a site, particularly temperature, aspect, sun/shade, and humidity, will affect vegetative cover and can have significant impacts on vegetative establishment and durability.

Other environmental considerations include the existence of sensitive ecosystems (if any) and land use in the area. Vegetative control designs should be compatible with existing land use.

The successful functioning of a vegetative control in removing pollutants from highway runoff can have adverse effects upon the vegetation comprising the control mechanism. Where the runoff contains a high concentration of suspended solids, sedimentation can bury grass and other low-growing vegetation, negating its ability to cleanse the runoff. Settling of small silt-like particles may clog soil pores reducing infiltration rates. The Florida DOT has had problems with some vegetated waterways becoming clogged by sediments. Accumulation of pollutants, particularly heavy metals in the soils of the vegetated waterways or filter strips creates potential adverse impacts. The probability of the eventual release of the pollutants depends on pollutant solubility and the pH of the runoff. Wang et al. (1981) found that in all cases, metal release from roadside soils increased as pH decreased. Lead and zinc were most sensitive to changes in pH. Bell and Wanielista (1979) recommend that soils (adjacent to pavements) receiving highway runoff as overland flow need to be replaced on a periodic basis due to metal saturation. The contaminated soil should be disposed of, so as to minimize adverse impacts. However, Washington DOT has observed that vegetated waterways do not become so saturated that they significantly lose their effectiveness.

The use of vegetative control measures for highway runoff can have beneficial effects in addition to the runoff cleansing and infiltration function. Vegetative controls, particularly filter strips, can enhance wildlife by providing additional habitat. Aesthetics may also be augmented through careful design, plant selection and site selection.

A filter strip planted with the secondary purpose of enhancing wildlife should be at least 150 m along with a minimum width of 7.5 m. Where shrubs are used, the strip should be a minimum of two rows of shrubs 4.8 m wide. Double rows with staggered spacing are preferred for wildlife enhancement. Species diversity also increases wildlife benefits. Shrubs and grass may be combined in filter strips to provide increased habitat availability. Plants should be carefully selected so as to maximize pollutant removal and wildlife value while minimizing species which may compete with or threaten native vegetation.

The major cost item in the use of vegetative controls for highway stormwater runoff is the land requirement. The amount of land needed will be dependent upon several parameters, including soil conditions (e.g. permeability), topography, precipitation patterns and quantity, and the pollutant removal objectives. Price of the land is variable and subject to fluctuation according to several factors (e.g. local land value, land use, development potential, etc.). Construction costs are also highly variable, although development of vegetative controls during initial highway construction would be less expensive. Costs of vegetation establishment and maintenance are relatively well known as part of normal highway construction and maintenance.

In summary, the use of vegetative controls (vegetated waterways, filter strips, and overland flow) is an effective

mitigation measure for control of highway stormwater runoff. Pollutant removal is consistently high, particularly for suspended solids and heavy metals. Vegetative control is applicable wherever suitable land area is available. The vegetation acts to reduce runoff velocity, enhancing sedimentation and filtration of suspended solids, increasing infiltration and allowing greater opportunity for adsorption and uptake by plants. Biological and chemical breakdown of pollutants occurs in the soil. However, specific data relating to design to pollutant removal effectiveness are limited. Design is therefore a matter of judgment based on local conditions and a concern for erosion prevention. Slope and soil permeability are principal design factors. As a general rule, a grassed waterway should be about 60 to 80 m long. Overland flow areas should also be approximately 60 to 80 m, although smaller filter strips are effective as well. According to the pollutant removal objectives and local conditions, larger or smaller areas may be necessary. Costs will be highly variable by site, primarily due to land values.

Wetland Treatment - "Wetland" is a general term for low-lying lands where the water table is usually at or near the surface, or the ground is inundated by precipitation, decomposition and chemical adsorption. Biological processes are primarily vegetative uptake and removal, with some biological transformation and degradation occurring. Many of these processes are interrelated, and are variable for different pollutants.

The pollutant removal processes are not all equally effective, and their prevalence may differ among wetlands. As the majority of waterborne pollutants are adsorbed to particulate matter, sedimentation acts to scrub the water

column and prevents dispersal of the pollutants. Sediments are further bound in place by plant roots and additional layers of sediment.

The effectiveness of wetlands for pollutant removal from surface waters varies by wetland type and site-specific parameters. Wetland pollutant removal efficiencies are influenced by hydraulic retention time, slope, fetch, surface area, salinity, pH, water level fluctuations, depth of standing water, soil substrate characteristics, plant and animal species and interactions, the percent of standing water versus channel flow, loading and other factors. However, some general conclusions can be made; consistent reduction of BOD, suspended solids and heavy metals in wetland treatment of runoff, removal of organics (BOD and COD) is very good, nitrogen removal is consistently high, phosphorus removal is variable and not reliable, suspended solids removal is satisfactory but can vary significantly with loading, and heavy metal removal is variable from low to almost complete removal (Chan et al. 1982).

There are several factors which limit wetland effectiveness for mitigation of stormwater runoff pollutants.

- Seasonal and sporadic nature of runoff where a reliable water supply is needed for maintenance of wetland vegetation.

- High flows and flushing action associated with runoff events.

An additional factor affecting wetland treatment is the seasonal changes which affect most wetlands. Low winter temperatures leading to death or dormancy in plants lower metabolic rates, thus reducing nutrient and heavy metal

uptake. Pollutants in the dead portions of the plants may be returned to the water or substrate after decomposition. Deeper water systems are less likely to be adversely affected. Physical pollutant removal processes are also less apt to be affected by season than chemical or biological pollutant removal processes.

The proximity of natural wetlands or suitable sites for man-made wetlands to sources of runoff requiring treatment will affect their suitability. Wetlands also have a potential for creating nuisance (mosquitoes) and odour problems.

The retention of inorganic particulate matter is a key wetland process for pollutant removal from runoff, and is a virtual prerequisite for retention and removal of other pollutants. Sediment export from wetlands rarely exceeds import except during peak flows or "flushing" events, although some wetlands periodically erode.

Nutrient retention is defined as the storing of nutrients (primarily nitrogen and phosphorus) within wetland substrate or vegetation. Nutrient removal involves conversion of nitrogen nutrients to gaseous forms, subsequently released from the wetland. Nutrient retention can occur on a broad time continuum. Long-term retention is more significant for the wetland ecosystem, although short-term retention may have water quality benefits by maintaining or improving downstream nutrient levels, particularly during growing seasons when aquatic systems are nutrient-sensitive.

Nutrient retention and removal efficiency by wetlands is difficult to quantify. Nutrients are involved in biotic and abiotic processes with continual exchange between substrate, vegetation, water and atmosphere. Net storage or release of

nutrients is a site-specific factor, although most wetlands tend to retain nutrients, at least during the growing season.

The results of the literature search indicate that under certain conditions, wetlands may, indeed, be appropriate to treat highway runoff. The type of wetland used (vegetation, sediment and hydrology), climatic and geographic characteristics, quality and quantity of pollutants which accumulate on the highway surface, the method of conveying the stormwater runoff to the wetland and the ratio of highway runoff to total watershed runoff appear to be primary considerations. The literature survey revealed considerable variability in highway runoff quality and in the ability of wetlands to withstand impact from highway runoff constituents or to treat highway runoff constituents. Therefore, treatment capacity is best evaluated on a system (highway/wetland) by system basis. However, the following wetland types appear most appropriate for highway runoff entrapment.

- Moss-lichen type - Organic substrate, surface saturated. This type is the most difficult to maintain because peat has a high capacity for storage and any fluctuation in the hydrologic cycle invites invading species and system deterioration.

- Emergent type - Organic substrate, shallow or surface-saturated.

- Scrub-shrub type - Organic substrate, shallow or surface-saturated.

- Forest type - Organic substrate, shallow or surface-saturated.

B.3.2 Detention Ponds

The alternative of temporarily storing highway storm water runoff to achieve both flood control and pollutant reduction benefits originates from the activities in storm water management. The most frequently used alternatives in urban storm water management are parking lot and rooftop storage and detention basins, wet or dry. Detention basins provide the primary pollutant reduction benefits.

The most recent information on pollutant removal effectiveness of detention basins comes from the US EPA Nationwide Urban Runoff Program (1983). The results of the extensive investigations carried out under the program concluded that the performance of dry basins ranged from insignificant to quite poor, when it comes to pollutant removal. On the other hand, wet basins were capable of removing effectively the pollutants from runoffs. However, the individual performance of the wet basins ranged from poor to excellent. The results of the investigations showed that in addition to sedimentation, some wet basins reduce the nutrient levels through biological processes.

Maryland monitoring studies showed that sediment traps could capture at least 92% of the sediments, generally smaller storms produced better removal efficiency. (Lynard et al., 1980).

Whipple and Hunter (1981) found that over a 32 hour settlement period, a 1.8 m deep pool removed substantial quantities of the common pollutants. Suspended solids, lead and hydrocarbons almost completely settled within the 16 hours. Other pollutants, such as BOD, Copper, Nickel and Zinc results were more irregular. The investigation found that the assumption

that pollutants will settle in amounts proportional to their respective particulate concentrations is not supported by the data.

Taylor (1980), found that detention ponds reduced the suspended fractions, ranging from 50% for TSS to 20% for Pb, with the addition of alumn coagulation, TSS removal averaged 90%.

In summary, wet detention basins, are capable of providing effective pollutant removal for highway runoff. The design and the basin size in relation to the drainage area are the key parameters affecting performance capability. Wet basins have the greatest pollutant removal capabilities, as biological processes in the permanent pool can produce significant reductions in soluble nutrients, in addition to the physical settling of particles. Dry basins are ineffective for reducing pollutant loads (US EPA, 1983).

Dual purpose basins, which are dry basins with a modified outlet structure that extends runoff detention time, have been showing promising results. Although these basins showed effective pollutant reductions, the biological processes affecting soluble nutrients were not apparent. Nevertheless, the dual purpose basins appear to be more cost effective than wet basins and are showing potential for converting existing dry basins to an effective pollutant reduction measure.

Experiments carried out in U.K. with sedimentation chambers and lagoons are reported by Harwood's (1986). The sedimentation chamber was 3.5 m x 0.7 m and 0.6 m deep with a 150 mmØ inlet and outlet pipe.

The lagoon was constructed in a 2 m wide 0.3 m deep V-shaped ditch. The invert was lined with 1.5 mm polythene sheets. The results of the monitoring of the two detention facilities are presented below.

	Removal Efficiency (%)		Loading (kg/km/year)	
	Tank	Lagoon	Tank	Lagoon
TSS	52	92	720	120
TPb	40	90	2.4	0.4
TZn	47	76	4.2	1.9
Zn (SA)	57	84	-	-
Zu (D)	15	62	-	-
CUD	35	54	-	-
Oil	30	>70	<88.2	<37.8
PAH	30	>70	12.6×10^{-3}	5.4×10^{-3}

B.3.3 Filtration Systems

Filters are primarily used for sediment control measures and are typically temporary in nature. As the pollutant removal capabilities are limited to the larger size suspended solids, filtration systems are not considered very effective for mitigation of highway storm water runoff pollution. The common filtration systems used mainly for temporary mitigation at problem areas include straw bale barriers, filter cloth fences and gravel filters. The advantages of filter systems are the removal of coarse sediments and the reduction of runoff velocity. Disadvantages include the poor structural strengths, frequent undercutting, piping or end flow, and the need for periodic maintenance to remove trapped sediment. Maintenance may be required after every storm event where the solid loads are significant. No information is available describing pollutant removal effectiveness.

Tourbier and Westmacott (1980) note that filter systems are only effective for small watersheds, generally less than 0.2 - 0.4 ha, and slope lengths should not exceed 30 m.

B.3.4 Flow Alteration

The flow alteration systems alter the hydraulic flow in order to minimize potential erosion and to reduce pollutant levels. The most common methods are; diversion, drop structures, slope drains and level spreaders. Diversion converts sheet flows into channel flow, drop structure reduces flow velocity, level spreaders convert channel flow to sheet flow and slope drains convey flow down on a slope.

There is no data available on the pollutant removal capabilities of flow alteration methods. The alternatives used are mainly for erosion control and have little direct impact on pollutants entrained in highway runoff. Some pollutant reductions may be achieved through sediment deposition encouraged by the flow alterations.

B.3.5 Catchbasins

The main purpose of catchbasins is to prevent sewer clogging by trapping large debris before it enters the sewer system and provide a water seal to prevent odour coming from the sewers. Catchbasins are perceived to have the ability to trap suspended solids in runoff. During the runoff event two functions occur simultaneously within a catchbasin:

1. Dissolved solids and some particulate solids within the catchbasins are re-suspended and swept out by the runoff along with the catchbasin effluent.

2. Large particulate solids in the incoming runoff settle out in the catchbasin.

The relative balance between these two functions is the key to whether a catchbasin is a benefit or a detriment. Unfortunately, most of the pollutants in street surface runoff are adsorbed to the fine particles, catchbasins are ineffective in preventing pollutants from entering the sewers or receiving waters. Also, catchbasins are ineffective as a storm water management practice, because of their small size in relation to the contributing drainage area. Basins, which are frequently cleaned, have the capacity for retaining coarse solids and any associated pollutants, but most catchbasins are not frequently cleaned. Effluents from dirty catchbasins can pose a significant pollution load, particularly during the first flush event.

The literature (Lager et al., 1977) shows that:

1) Properly designed and maintained catchbasins can be very efficient in removing medium to very coarse sands, larger than 1.0 mm in diameter, from storm water runoff. But removal of fine sands ranged from fair to poor with increasing flow.

2. Storage basin depths is the primary control for performance. Efficiencies improve with increasing depths.

3. The accumulation of sediment in catchbasins does not appear to impair solid removal efficiencies, until approximately 50% of the storage depth is filled. Beyond this depth, removal drops rapidly, even to the point of negative values, where wash-out exceeds sedimentation.

4. Catchbasins exhibit mixed performance with respect to pollution control. The trapped liquid purged from catchbasins to the sewers during each storm generally has a high pollutant content.

5. Approximately 95% of the BOD_5 load in a liquid contained in a catchbasin prior to a storm will be displaced to the sewer by a rainfall of as little as 0.05 cm/hr, lasting four hours. This is approximately equivalent to the waste discharged by one person in one day.

6. The removal of heavy metals appear to be quite significant in a catchbasin and can range from 40% to 60%. Sump sediments were found to be highly organic.

In summary, catchbasins are only effective in removing coarse solids from stormwater runoff. Frequent cleaning of catchbasins removes the accumulated pollutant. However, few catchbasins are adequately maintained due to the high cost. Where the receiving water has the velocity and flow to carry the suspended solids without creating sediments, catchbasins should be replaced with simple inlets, designed to trap only large debris allowing the runoff to enter the sewer system without settling.

B.4 SUMMARY OF POLLUTION CONTROL MEASURES

A review of the numerous pollution control measures identified only four cost-effective alternatives:

- Vegetative Controls
- Wet Detention Basins
- Infiltration Basins
- Wetlands, where available

Vegetative controls include vegetated drainage-ways, filter strips and overland flow. These controls use the natural capability of vegetated surfaces to reduce velocity of runoff and enhance sedimentation, filtration and infiltration of runoff contaminants. Grass is the typical vegetation used.

Wet detention basins are those basins, ponds or lakes with a permanent pool to receive runoff inflow. Settling of suspended materials is the primary pollutant removal action, although some biological removal of nutrients also occurs.

Infiltration systems include systems which infiltrate collected runoff, such as basins, drainage wells, deep injection wells, shallow infiltration pits and trenches. Pollutant removal occurs in the soil and is thus highly site dependent. Sediment may clog soil pores.

Wetland treatment utilizes wetland ecosystems (characterized by high floral productivity and nutrient needs, high decomposition rates and low oxygen content in the sediments and substrate) to assimilate large quantities of runoff contaminants. Use of wetlands to mitigate highway runoff pollution is limited by several factors and is not adequately documented. However, potential pollutant removals are high.

Several management practices were identified as being ineffective or insignificant in terms of pollution abatement. These practices are, however, often conducted primarily to achieve objectives other than stormwater runoff pollution mitigation, such as aesthetics, public relations and safety. They include:

- Litter Controls - Litter controls include safe disposal methods, public education, periodic cleanups and anti-litter regulations. Litter control programs are primarily for aesthetic purposes and are ineffective in addressing highway runoff pollution.

- Street Cleaning - Street cleaning is a common practice for many municipal areas, with dual goals of aesthetics and pollutant removal. Street cleaning does not remove the smaller-sized sediments and other materials which are associated with most of the highway runoff pollutant loadings.

- Filtration Systems - Filtration devices are typically short-term in nature and designed to limit sediment loads in runoff. They are effective only at removing the larger suspended sediment and solid particles, and are ineffective at removing highway runoff contaminants. Filtration systems include straw bale barriers, filter cloth fences, and gravel filters.

- Catchbasins - Catchbasins can be effective in protecting sewers from coarse solids and debris; however, pollutants associated with fine particles will enter the sewer or receiving water. There is also a tendency for some of the materials in the catchbasin sludge to be resuspended and released, even at low to moderate inflow rates.

- Dry Detention Basins - Detention times are generally too short to allow sedimentation to occur. Furthermore, materials removed may be washed out by subsequent runoff.

- Porous Pavement - Structural inadequacies and maintenance of dry sub-bases exclude this option.

LITERATURE CITED

ABAG, "Treatment of Stormwater Runoff by a Marsh/Flood Basin, "Association of Bay Area Governments, Interim Report to U.S. Environmental Protection Agency, August 1979.

Amimoto, Perry Y., "Erosion and Sediment Control Handbook," California Department of Conservation, EPA 440/3-78-003, U.S. Environmental Protection Agency, Water Planning Division, Washington, D.C., May, 1978.

Becker, Burton C., Michael L. Clar, and Robert R. Kautzman, "Approaches to Stormwater Management," U.S. Department of Interior, Office of Water Resources Research, Washington, D.C., November 1973.

Chan, Emy, Gary Silverman, and Terry Bursztynsky, "San Francisco Bay Area Regional Wetlands Plan for Urban Runoff Treatment - Volume I Plan and Amendments to the Environmental Management Plan", Draft Report, Association of Bay Area Governments, Berkeley, CA, December 1982.

Colwill, D.M., C.J. Peters, and R. Perry, "Water Quality of Motorway Runoff", TRRL Supplementary Report 823, U.K., 1984.

Dillon, M.M. Ltd., Salt Budgeting for Water Resource Protection, Roads and Transportation Association of Canada, 1989.

Harwood, E., "Effects of Land Use on Fresh Waters", Chapter 3, Impact of Motorway Runoff upon Surface Water Quality, written by R. Perry and A.E. McIntyre, 1986.

Hedley, G., and J.C. Lockley, "Quality of Water Discharged from an Urban Motorway", Water Pollution Control, 1975, pp.659-674.

Jackura, Kenneth A., "Infiltration Drainage of Highway Surface Water", Report No. FHWA/CA/TL-80/04, California Department of Transportation, Office of Transportation Laboratory, Sacramento, CA., July 1980.

Kerri, K.D., et al., "Forecasting Pollutant Loads from Highway Runoff", Transportation Research Record, Vol. 1017, pp. 39-46, 1985.

Kobriger, N.P., et al., "Constituents of Highway Runoff", Vol. III. Federal Highway Administration, 1981.

Kobriger, N.P., T.V. Dupuis and W.A. Kreutzberger, "Effects of Highway Runoff on Wetlands", 1984.

Kobriger, N.P. and A. Geinepolos, "Sources and Migration of Highway Runoff Pollutants", 1984.

Kobriger, N.P., M.K. Gupta and A. Geinopolos, "Sources and Migration of Highway Runoff Pollutants", Report No. FHWA/RD, Federal Highway Administration, Washington, D.C., October 1982.

Lager, John A., William G. Smith and George Tchobanoglous, "Catchbasin Technology Overview and Assessment", EPA-660/2-77-051, U.S. Environmental Protection Agency, Cincinnati, Ohio, May 1977.

Lygren, E. Gjessing, L. Berglind, Norwegian Institute for Water Research 1984. Pollution Transport From a Highway. The Science of the Total Environment, 33 (1984) 147-159. Elsevier Science Publishers B.V., Amsterdam.

Lynard, William G, John Finnemore, Joseph A. Loopp and Robert M. Finn, "Urban Stormwater Management and Technology: Case Histories, "EPA 600/8-80-035, U.S. Environmental Protection Agency, Cincinnati, Ohio, August 1980.

Mar, Brian W., Richard B. Horner, John F. Ferguson, Dimitris E. Spyridakis, and Eugene B. Welch, "Highway Runoff Water Quality", Washington State Department of Transportation, Seattle, Washington, March 1982.

Poland, Claudius, "Grassed Waterway Design", in U.S. Environmental Protection Agency "Non-Point Source Pollution Seminar Section 108(a) Demonstration Projects Progress Reports," EPA 905/0-75-007, U.S. Environmental Protection Agency, Chicago, Illinois, 1975.

Stotz, Investigation of the properties of the surface runoff from Federal Highways in Germany. The Science of the Total Environment 59 (1987) 329-337.

Taylor, J.S., P. Moore, V. Godlewski and B.A. Snyder, "Coagulation and Detention of Stormwater Runoff", Annual Meeting of the American Society of Civil Engineers, October 27 to 31, 1980, Hollywood, Florida, University of Central Florida, Civil Engineering Dept. Gainesville, FL. 1980.

Tourbier, J. Toby (ed)., and Richard Westmacott (ed.), "Stormwater Management Alternatives", University of Delaware, Water Resources Center, Newark, DE., April 1980b.

U.S. Department of Transportation, "Design of Urban Highway Drainage, The State of the Art", Report No. FHWA-TS-79-225, Department of Transportation, Federal Highway Administration, Washington, DC, 1979.

U.S. Environmental Protection Agency, "Final Report of the Nationwide Urban Runoff Program, Vol. 1", U.S. Environmental Protection Agency, Washington, DC, September 1983.

VSWCC, "Virginia Erosion and Sediment Control Handbook", Second Edition, Virginia Soil and Water Conservation Commission, Richmond, VA, 1980.

Wang, Tzn-Siang, Dimitris E. Spyridakis, Brian W. Mar, and Richard R. Horner, "Transport, Deposition and Control of Heavy Metals in Highway Runoff", Washington State Dept. of Transportation, Seattle, WA., January 1981.

Weaver, Robert J., "Recharge Basins for Disposal of Highway Storm Drainage", Research Report 69-2, New York State Department of Transportation, Albany, NY, May 1971.

Westerman, Philip W., Michael R. Overcash, and Samuel C. Bingham, "Reducing Runoff Pollution Using Vegetated Borderland for Manure Application Sites", EPA-600-52-83-022, U.S. Environmental Protection Agency, Ada, OK.

Whipple, William Jr., and Joseph V. Hunter, "Settleability of Urban Runoff Pollution", Journal WPCF, Vol. 53, No. 12, December 1981, pp. 1726 to 1731.

Yousef, Y.A., Wanielista, M.P. and Harper, H.H., "Removal of Highway Contaminants by Roadside Swales", Transportation Research Record 1017, U.S. Transportation Research Board, 1985.

APPENDIX

WATER QUALITY CRITERIA OF HIGHWAY RUNOFF

U.S. Environmental Protection Agency, "Water Quality Criteria Documents; Availability." Federal Register, Vol. 45, No. 231 (1980) pp. 79318-79379.

U.S. Environmental Protection Agency, "Quality Criteria for Water." EPA-400/9-76-023 (1976) 256 p.

Summary of water quality criteria for possible constituents of highway runoff

Constituent	Description of Critical Level	Year of Criteria Issuance	Basis for Criteria or Water Use
Suspended solids	Should not reduce the depth of the compensation point for photosynthetic activity by more than 10% from the seasonally established norm for aquatic life	1976	Freshwater fish and other aquatic life
Ammonia	0.02 mg/l (un-ionized as NH_3-N)	1976	Freshwater aquatic life
Dissolved oxygen	Greater than or equal to 5.0 mg/l	1976	Freshwater aquatic life
Phosphorus	0.10 g/l (elemental)	1976	Marine or estuarine waters
Nitrate	10 mg/l (as N)	1976	Domestic water supply (health)
Chlorides	250 mg/l	1976	Domestic water supply (welfare)
Sulfates	250 mg/l	1976	Domestic water supply (welfare)
Lead, g/l (total recoverable)	$e^{(2.35[\ln(\text{hardness})]-9.24)}$ 24-hour average	1980	Freshwater aquatic life
	$e^{(1.22[\ln(\text{hardness})-0.47)}$ (not to exceed)	1980	Freshwater aquatic life
	668 g/l (acute toxicity*)	1980	Saltwater aquatic life
	25 g/l (chronic toxicity*)	1980	
	50 g/l	1980	Human health
Cadmium (total recoverable)	$e^{(1.05[\ln(\text{hardness})]-3.73)}$ (not to exceed)	1980	Freshwater aquatic life

* Specified as the lowest level that toxicity has been measured for certain organisms; other organisms could be affected at lower levels.

Summary of water quality criteria for possible constituents of highway runoff (continued).

Constituent	Description of Critical Level	Year of Criteria Issuance	Basis for Criteria or Water Use
Arsenic	440 mg/l (not to exceed)	1980	Freshwater aquatic life
	508 g/l (acute toxicity*)	1980	Saltwater aquatic life
	Zero (cancer risk levels also specified)	1980	Human health
Cyanides (free cyanide)	3.5 g/l (24-hr average)	1980	Freshwater aquatic life
	52 g/l (not to exceed)	1980	
	30 g/l (acute toxicity*)	1980	Saltwater aquatic life
	2.0 g/l (chronic toxicity*)	1980	
	200 g/l (ingestion of water and contaminated organisms)	1980	Human health
Asbestos	No toxicity date available for aquatic organisms	1980	Aquatic life
	Zero (cancer risk levels also specified)	1980	Human health
PCB	0.014 g/l (24-hr average)	1980	Freshwater aquatic life
	0.030 g/l (24-hr average)	1980	Saltwater aquatic life
	Zero (cancer risk levels also specified)	1980	Human health
Oil & Grease	0.01 times lowest continuous flow 96-hr LC_{50} for several important freshwater species; minimize sediment levels; surface waters free from floating oils	1976	Freshwater aquatic life

* Specified as the lowest level that toxicity has been measured for certain organisms; other organisms could be affected at lower levels.

Summary of water quality criteria for possible constituents of highway runoff (continued).

Constituent	Description of Critical Level	Year of Criteria Issuance	Basis for Criteria or Water Use
Nickel (cont.)	7.1 g/l (24-hr average)	1980	Saltwater aquatic life
	140 g/l (not to exceed)	1980	
	13.4 g/l (ingestion of water of water & contaminated organisms)	1980	Human health
	100 g/l (ingestion of contaminated organisms alone)	1980	Human health
Zinc (total) recoverable)	47 g/l (24-hr average)	1980	Freshwater aquatic life
	$e^{(0.83[\ln(\text{hardness})] + 1.95)}$ (not to exceed)	1980	Freshwater aquatic life
	58 g/l (24-hr average)	1980	Saltwater aquatic life
	170 g/l (not to exceed)	1980	
	5 mg/l	1980	Taste & odor
Mercury (total recoverable)	0.00057 g/l (24-hr average)	1980	Freshwater aquatic life
	0.0017 g/l (not to exceed)	1980	
	0.025 g/l (24-hr average)	1980	Saltwater aquatic life
	3.7 g/l (not to exceed)	1980	
	144 ng/l (ingestion of water and contaminated organisms)	1980	Human health
	146 ng/l (ingestion of contaminated organisms alone)	1980	Human health
Iron	0.3 mg/l	1976	Domestic water supply(welfare)
	1.0 mg/l	1976	Freshwater aquatic life
Manganese	50 g/l	1976	Domestic water supply(welfare)
	100 g/l	1976	Ingestion of marine mollusks

* Specified as the lowest level that toxicity has been measured for certain organisms; other organisms could be affected at lower levels.

U.S. EPA TRACE METAL CRITERIA FOR URBAN RUNOFF

Table 1. U.S. EPA Trace Metal Criteria For Urban Runoff Exposure

TRACE METAL CONTAMINANT	WATER HARDNESS (mg/l as CACO3)	HUMAN[2] INGESTION (Food/Drink) (ug/l)	AMBIENT LIFE CRITERIA FOR INTERMITTENT EXPOSURE (ug/l)[3] Threshold[4] Effect	Significant[5] Mortality
Copper	50	-	20	50-90
	100	-	35	90-150
	200	-	80	120-350
Cadmium	50	10	3	7-160
	100	10	6.6	15-350
	300	10	20	45-1070
Lead	50	50	150	350-3200
	100	50	360	820-7500
	200	50	850	1950-17850
Zinc	50	-	380	870-3200
	100	-	680	1550-4500
	200	-	1200	2750-8000
Nickel	-	13.4	-	-

[2] Derived from EPA drinking water criteria.

[3] EPA estimate of toxicity under intermittent, short duration exposure (several hours once every several days).

[4] Concentration causing mortality to the most sensitive individual of the most sensitive species.

[5] Significant mortality shown as a range: 50% mortality in the most sensitive species, and mortality of the most sensitive individual in the species in the 25th percentile of sensitivity.

U.S. Environmental Protection Agency (EPA). 1983. Results of the Nationwide Urban Runoff Program. Volume I. Final Report. Water Planning Division. Washington, DC. 159 pp.

A MODEL BY-LAW
TO CONTROL
WASTE DISCHARGES
TO
MUNICIPAL SEWERS

Prepared by a Committee represented by:

The Ontario Ministry of the Environment

Environment Canada

The Ontario Municipal Engineers Association

SECTION 3

DISCHARGES TO STORM SEWERS

3(1) No person shall discharge or deposit or cause or permit the discharge or deposit of matter of a kind listed below into or in land drainage works, private branch drains or connections to any storm sewer,

1. matter of any type or at any temperature or in any quantity which may:

   (a) interfere with the proper operation of a storm sewer;

   (b) obstruct a storm sewer or the flow therein;

   (c) result in a hazard to any person, animal, property or vegetation;

   (d) impair the quality of the water in any well, lake, river, pond, spring, stream, reservoir or other water or watercourse; or

   (e) result in the contravention of an approval, requirement, direction or other order under the Ontario Water Resources Act or the Environmental Protection Act (Ontario) with respect to the storm sewer or its discharge; and

2. without limiting the generality of the foregoing, any of the following:

   (a) water at a temperature greater than 40° Celsius;

   (b) water having a pH less than 6.0 or greater than 9.0;

   (c) water containing more than 15 milligrams per litre of suspended solids;

   (d) water containing dyes or colouring material which discolour the water;

   (e) water containing solvent extractable matter of animal or vegetable origin or of mineral or synthetic origin which causes a visible film, sheen or discolouration on the water surface;

   (f) water containing any of the following in excess of the indicated concentrations:

   200 micrograms/litre

   Chromium expressed as Cr

50 micrograms/litre

Zinc expressed as Zn
Lead expressed as Pb
Nickel expressed as Ni

10 micrograms/litre

Copper expressed as Cu

1 microgram/litre

Cadmium expressed as Cd
Mercury expressed as Hg

200 per 100 millilitres

Fecal coliforms

(g) the following matter in any amount:

Sewage
Once-through cooling water
Blowdown

(h) the following materials in any amount:

Automotive or Machine Oils and Greases
Fuels
Paints and Organic Solvents
PCBs
Pesticides
Severely Toxic Materials
Waste Disposal Site Leachate
Waste Radioactive Materials

(i) the following hazardous wastes in any amount:

Acute Hazardous Waste Chemicals
Hazardous Industrial Wastes
Hazardous Waste Chemicals
Ignitable Wastes
Pathological Wastes
PCB Wastes
Reactive Wastes

3(2) Subclause 3(1) 2.(g) does not apply to prevent the discharge of once-through cooling water or blowdown when,

(a) the once-through cooling water or blowdown is being discharged pursuant to a certificate of approval or order relating to the premises under the Environmental Protection Act (Ontario) or the Ontario Water Resources Act which expressly allows the discharge;

(b) the owner or operator of the premises has written approval from the municipality which expressly authorizes the discharge from the premises; and

WATER MANAGEMENT

– Goals, Policies, Objectives
and Implementation Procedures
of the Ministry of the Environment

Ontario Ministry
of the
Environment

November, 1978

Table 1
Provincial Water Quality Objectives

INORGANICS AND OTHER PARAMETERS

Alkalinity and pH — Alkalinity should not be decreased by more than 25% of the natural concentrations. The pH should be maintained within the range 6.5-8.5.

***Ammonia** — Concentrations of un-ionized ammonia should not exceed 0.02 mg/L for the protection of aquatic life.

The percentages of un-ionized ammonia in aqueous ammonia solution for different temperature and pH conditions are listed below:

Temperature °C	pH 6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
5	0.013	0.040	0.13	0.39	1.2	3.8	11	28.	56.
10	0.019	0.059	0.19	0.59	1.8	5.6	16.	37.	65.
15	0.027	0.087	0.27	0.86	2.7	8.0	22.	46.	73.
20	0.040	0.13	0.40	1.2	3.8	11.	28.	56.	80.
25	0.057	0.18	0.57	1.8	5.4	15.	36.	64.	85.
30	0.081	0.25	0.80	2.5	7.5	20.	45.	72.	89.

For example, at 20°C and pH 8.0, a total ammonia concentration of 0.5 mg/L would give an un-ionized concentration of 0.5 x 3.8/100 = 0.019 which is less than the un-ionized Objective of 0.02.

Chlorine — Total residual chlorine, as measured by the amperometric (or equivalent) method, should not exceed 0.002 mg/L.

Cyanide — Concentrations of free cyanide in unfiltered sample should not exceed 0.005 mg/L.

*Under certain temperature and pH conditions, the total ammonia criterion for the protection of aquatic life may be less stringent than the criteria for other beneficial uses.

Dissolved Gases — To protect aquatic organisms, the total dissolved gas concentrations in water should not exceed 110 percent of the saturation value for gases at the existing atmospheric and hydrostatic pressures.

Dissolved Oxygen — At no time should dissolved oxygen concentrations be less than the values specified below:

Temperature °C	Dissolved Oxygen Concentration Cold Water Biota % Saturation	mg/L	Warm Water Biota % Saturation	mg/L
0	54	8	47	7
5	54	7	47	6
10	54	6	47	5
15	54	6	47	5
20	57	5	47	4
25	63	5	48	4

In situations where additional physical and/or chemical stresses are present these minimum levels may prove inadequate and more stringent Objectives may be necessary.

In some hypolimnetic waters, dissolved oxygen is naturally lower than the above-specified concentrations. Such a condition should not be altered by adding oxygen demanding materials causing a depletion of dissolved oxygen.

Hydrogen Sulfide — Concentration of undissociated hydrogen sulfide should not exceed 0.002 mg/L, at any time or place, to protect aquatic life.

Oil and Grease — Oil or petrochemicals should not be present in concentrations that:

– can be detected as a visible film, sheen, or discolouration on the surface;

– can be detected by odour;

– can cause tainting of edible aquatic organisms;

– can form deposits on shorelines and bottom sediments that are detectable by sight or odour, or are deleterious to resident aquatic organisms.

Phenols

Concentrations of phenols should not exceed 1 μg/L to protect against tainting of edible fish flesh.

Phosphorus, Total

Current scientific evidence is insufficient to develop a firm Objective at this time. Accordingly, the following phosphorus concentrations should only be considered as general guidelines which should be supplemented by site-specific studies:

To avoid nuisance concentrations of algae in lakes, average total phosphorus concentrations for the ice-free period should not exceed 20 μg/L;

A high level of protection against aesthetic deterioration will be provided by a total phosphorus concentration for the ice-free period of 10 μg/L or less. This should apply to all lakes naturally below this value;

Excessive plant growth in rivers and streams should be eliminated at a total phosphorus concentration below 30 μg/L.

Radionuclides

Radiation exposure should be kept as low as reasonably achievable, economic and social factors being taken into account.

Radioactive materials should not be present in receiving waters as a consequence of the failure of an installation to exercise practical and economic controls to minimize releases.

Regardless of economic factors, the dose equivalent to individuals consuming the waters must not exceed the limits recommended for the appropriate circumstances by the Atomic Energy Control Board.

Water quality objectives based on these considerations will ensure that fish and other aquatic life will not receive hazardous doses of radiation.

Present objectives are as follows:

Gross beta emitters	1000 pCi/L
Radium-226	3 pCi/L

Where other radioisotopes occur, their significance should be assessed for each situation with respect to the potential hazard to humans and to aquatic life.

Temperature

1) General

The natural thermal regime of any body of water shall not be altered so as to impair the quality of the natural environment. In particular, the diversity, distribution and abundance of plant and animal life shall not be significantly changed.

2) Waste Heat Discharge

(a) Ambient Temperature Changes

The temperature at the edge of a mixing zone shall not exceed the natural ambient water temperature at a representative control location by more than 10C° (18F°). However, in special circumstances, local conditions may require a significantly lower temperature difference than 10C° (18F°). Potential dischargers are to apply to the Ministry of the Environment for guidance as to the allowable temperature rise for each thermal discharge. This Ministry will also specify the nature of the mixing zone and the procedure for the establishment of a representative control location for temperature recording on a case-by-case basis.

(b) Discharge Temperature Permitted

The maximum temperature of the receiving body of water, at any point in the thermal plume outside a mixing zone, shall not exceed 30°C (86°F) or the temperature at a represen-

tative control location plus 10°C (18°F) or the allowed temperature difference, whichever is the lesser temperature. These maximum temperatures are to be measured on a mean daily basis from continuous records.

(c) Taking and Discharging of Cooling Water

Users of cooling water shall meet both the Objectives for temperature outlined above and the "Procedures for the Taking and Discharge of Cooling Water" as outlined in the Implementation Procedures for Policy 3 (page 15).

Total Dissolved Solids	Dissolved Solids must not be added to increase the ambient concentrations by more than 1/3 of the natural concentrations to protect aquatic life. The added solids should not significantly alter the overall ionic balance of the receiving waters.
Turbidity	Suspended matter should not be added to surface water in concentrations that will change the natural Secchi disc reading by more than 10 percent.

HEAVY METALS

The following metal Objectives (except for mercury) are based on the total concentration of an unfiltered water sample. It is recognized that metals may not be toxic in particulate or bound form. It is quite possible for the total concentration in a given surface water to exceed the Objective without damaging any aquatic life. However, in the absence of any standard technique to measure the toxic components, it is assumed that all of the metal is in a toxic form unless specific data show otherwise. Further, an asterisk is placed before three parameters, namely arsenic, chromium and selenium, which have Objectives for aquatic life protection that are less stringent than the criteria for other beneficial uses.

*Arsenic	Concentrations of Arsenic in an unfiltered sample should not exceed 100 μg/L to protect aquatic life.
Beryllium	For the protection of aquatic life, concentrations of beryllium should not exceed 11 μg/L in an unfiltered sample of hardness less than 75 mg/L of $CaCO_3$ and not exceed 1100 μg/L in an unfiltered sample of hardness greater than 75 mg/L of $CaCO_3$.
Cadmium	Concentrations of cadmium in an unfiltered sample should not exceed 0.2 μg/L to protect aquatic life.
*Chromium	Concentrations of chromium in an unfiltered sample should not exceed 100 μg/L to protect aquatic life.
Copper	Concentrations of copper in an unfiltered sample should not exceed 5 μg/L to protect aquatic life.
Iron	Concentration of iron in an unfiltered sample should not exceed 300 μg/L to protect aquatic life.
Lead	The toxicity of lead is highly dependent on the alkalinity of the water. The toxicity declines as the alkalinity increases. The total lead concentration should not exceed the values given below:

Alkalinity mg/L as $CaCO_3$	Maximum lead Concentration μg/L
Up to 20	5
20 to 40	10
40 to 80	20
greater than 80	25

Mercury	Concentrations of total mercury in *filtered* water should not exceed 0.2 μg/L nor should the concentrations of total mercury in whole fish exceed 0.5 μg/g (See Table 2).
Nickel	Concentrations of nickel in an unfiltered sample should not exceed 25 μg/L to protect aquatic life.
*Selenium	Concentrations of Selenium in an unfiltered sample should not exceed 100 μg/L to protect aquatic life.

Silver	Concentrations of silver in an unfiltered sample should not exceed 0.1 μg/L to protect aquatic life.
Zinc	Concentrations of zinc in an unfiltered sample should not exceed 30 μg/L to protect aquatic life.
Unspecified Non-Persistent Toxic Substances and Complex Effluents	For non-persistent compounds or mixtures with no Objectives because of a lack of specific data, their concentration should not exceed 0.05 of the 96 hour LC50 value for any approved test species.

PESTICIDES

The wide-spread use of pesticides for the control of undesirable plant and animal life will continue for the foreseeable future. Ideally, application practices and pesticide formulations strive for maximum impact on the target organisms. However, strict adherence to sound application practices do not necessarily ensure an effective containment of the chemicals used. The physico-chemical properties of substances and environmental transport processes have introduced the pesticide chemicals into the aquatic environment, often with undesirable side-effects on non-target communities of the biota. The risks to aquatic ecosystems depend on the chemical and physical properties of the pesticides, type of formulations, method and rate of application and the nature of receiving waters. While acute toxicity data and usage characteristics are considerations in environmental assessments, organic compounds with bioaccumulative potential and resistance to degradation have so far presented the greatest hazard to human and aquatic life.

The following are Objectives for pesticides in widespread use in Ontario. Objectives for several other pesticides with sufficient data for establishing Objectives are also listed. Several pesticides commonly used in Ontario, which do not have criteria listed here due to lack of sufficient data, are listed in Table 3. Criteria will be established for these compounds upon collection and review of biological data but until that time objectives of generic compounds should be used as guidelines for acceptable concentrations.

	Maximum Concentration in μg/L (unfiltered sample)	Remark
Actively Used Herbicides in Ontario:		
Dicamba (Banvel)	200.0	
Diquat	0.5	
Diuron	1.6	
Dalapon	110.0	
Simazine	10.0	
2, 4-D (BEE)	4.0	
Actively Used Insecticides in Ontario:		
Chlordane	0.06	
Chlorphyrifos (Dursban)	0.001	
Diazinon	0.08	
Endosulphan	0.003	
Fenthion (Baytex)	0.006	
Guthion	0.005	
Malathion	0.1	
Methoxychlor	0.04	
Pyrethrum	0.01	

	Maximum Concentration in μg/L (unfiltered sample)	Remark
Other Pesticides Not Actively Used in Ontario:		
Aldrin/Dieldrin	0.001	a
DDT and Metabolites	0.003	b, See Table 2
Endrin	0.002	a
Heptachlor and Heptachlor epoxide	0.001	a
Lindane	0.01	a
Toxaphene	0.008	
Parathion	0.008	

a: The edible portion of fish should not exceed 0.3 μg/g for the protection of human consumers of fish.

b: The whole fish (wet weight basis) should not exceed 1 μg/g for the protection of fish consuming birds.

INDUSTRIAL ORGANICS

Thousands of synthetic organic chemicals are in daily use as raw materials, products and additives. The potential hazards posed by many industrial organics are poorly understood because many of these compounds are ill-defined, being by-products of a main reaction and of little commercial concern.

Unlike pesticides which are specifically designed to be toxic to some target organisms in the environment and whose environmental persistence and toxicity are documented and regulated under licencing laws, it is only in recent years that the significance of organic contaminants has become recognized. In general, they degrade slowly or not at all and are frequently bioaccumulative. Organisms such as fish can accumulate over a period of time, pollutant concentrations thousands or millions of times the minute pollutant level in water (usually as low as a few parts per trillion). This accumulation may have a long-term deleterious effect on aquatic species and on human health.

For the control of industrial organics and other toxic substances, the Ministry will make use of the Implementation Procedures outlined for the "Hazardous Substances" Policy (page 20-22).

The Objectives outlined below for a small number of industrial organics are based on current toxicity data. Adoption of these Objectives does not imply that more stringent criteria will not be necessary in the future if other deleterious effects are detected. Further, these Objectives are intended as guidance for dealing with past release or accidental losses, but not for new releases.

	Concentration in µg/L (unfiltered sample)	Remark
Dibutylphthalate	4.0	
Diethylhexylphthalate	0.6	
Other Phthalates	0.2	
Dechlorane (mirex)	0.001	See Table 2
Polychlorinated Biphenyl	0.001	See Table 2

SWIMMING AND BATHING USE OF WATER

Aesthetics

Water used for swimming, bathing and other recreational activities should be aesthetically pleasing. The water should be devoid of debris, oil, scum and any substance which would produce an objectionable deposit, colour, odour, taste or turbidity.

Discharge of Waste Materials

Discharge of waste and offensive materials due to land drainage or due to direct application to the water body must be curtailed or controlled in order to maintain recreational usage.

pH

Because both alkaline and acid waters may cause eye irritation, the pH of the water used for recreational purposes should be within the range of 6.5 and 8.5.

Water Clarity

The water in bathing areas should be sufficiently clear to estimate depth or to see submerged swimmers who may require assistance. To achieve this degree of safety, water clarity should be such that, if the bottom of the bathing area is not visible, the water should have a Secchi disc transparency of at least 1.2 m.

Public Health Considerations

The use of water for swimming, bathing and other recreational activities requiring immersion of the user should not cause disease(s) or infection(s) in the human user. Such disease(s), which may occur in the gastro-intestinal tract, the eye, ear, nose or throat or in the skin, could be caused by pathogens including bacteria, fungi, protozoa or viruses contained in the water.

A potential health hazard is defined as a situation where there is a high risk of contracting a disease from use of the water. In these situations: confirmation of the hazard should be sought; potential users should be notified by the appropriate authority; immediate corrective action should be started; and surveillance of the water quality should continue until the corrective action is completed and the water quality can be declared safe for recreational use.